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TECHNOLOGY FOR USE OF VARIABLE QUALITY FUELS

INTERIM REPORT
BFLRF No. 239

By

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This program was intended to determine the specification properties of diesel fuel that can be varied and relaxed with little or no performance or handling penalties by using modified bench and engine tests. Specially blended test fuels were used that had selected properties outside of specified limits in Federal Specification VV-F-800D, Fuel Oil, Diesel, Grade DF-2. The properties investigated were cetane number, viscosity, distillation temperature limits at 90-percent recovered and end point, accelerated stability values, and carbon residue on 10-percent bottoms. Cold-starting tests to investigate the effect of fuel cetane numbers and viscosities were conducted with engines common to the Army inventory as follows: Detroit Diesel 6V-53T, Continental LDT-465-1C, Cummins NHC-250, and General Motors 6.2L. The effect of higher 90-percent distillation and end-point temperatures than specified was investigated using a Petter model PH1W single-cylinder diesel engine. To investigate the effect of high accelerated stability values on injector deposit formation, several fuels were evaluated by the Injector Fouling Bench Test (IFBT) using two injector systems: the Detroit

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Diesel and the Bosch APE 113. The same methodology was used to investigate the effect of a fuel that exceeded the specification limit for carbon residue on injector deposit formation. The overall conclusions from this work are that the fuel properties investigated cannot be relaxed to any significant extent and still permit adequate long-term performance in all engines and components currently in the Army system under all climate conditions. Some engines and systems are very tolerant of fuels that do not meet current DF-2 specification requirements, while others will **not** operate satisfactorily on fuels that fail to meet certain specification limits. Using the least tolerant engines, the chemical and physical property limits for a variable quality fuel specification are suggested for limited time frame use on local procurements for high throughput maneuvers where ambient temperatures exceed 45°F (7°C).

Cold weather operations as well as vehicles experiencing low utilization require standard specification fuels for trouble-free operation.

FOREWORD

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TABLE OF CONTENTS

Section		Page
I.	INTRODUCTION	1
II.	OBJECTIVES	2
III.	APPROACH	3
IV.	EXPERIMENTAL AND DISCUSSION OF RESULTS	4
	A. Cetane Number and Viscosity	4
	1. Cold-Start Engine Tests	5
	2. Cold-Start Test Results	9
	3. Effect of Front-End Volatility and Viscosity on Fuel Injection Systems	21
	B. 90-Percent Distillation and End Point	22
	C. Accelerated Stability	24
	D. Carbon Residue	33
V.	SUMMARY OF RESULTS	39
VI.	CONCLUSIONS	40
VII.	RECOMMENDATIONS	41
VIII.	REFERENCES	42
APPENDICES		
A.	Army Cold Startability Procedure	45
B.	Cold-Start Test Data	49
C.	Injector Fouling Bench Test Methodology for Diesel Fuel Thermal Stability	55
D.	Diesel Fuel Specification Comparisons	63
E.	Interrelationship of Physical/Chemical Properties of Fuels	67

LIST OF ILLUSTRATIONS

Figure		Page
1	"40" Cetane Number Fuels - DD 6V-53T Engine	10
2	"35" Cetane Number Fuels - DD 6V-53T Engine	10
3	"30" Cetane Number Fuels - DD 6V-53T Engine	11
4	"40" Cetane Number Fuels - LDT-465-1C Engine	12
5	"35" Cetane Number Fuels - LDT-465-1C Engine	13
6	"30" Cetane Number Fuels - LDT-465-1C Engine	13
7	"40" Cetane Number Fuels - NHC-250 Engine	15
8	"35" Cetane Number Fuels - NHC-250 Engine	15
9	"30" Cetane Number Fuels - NHC-250 Engine	16
10	"40" Cetane Number Fuels - GM 6.2L Engine	17
11	"35" Cetane Number Fuels - GM 6.2L Engine	18
12	"30" Cetane Number Fuels - GM 6.2L Engine	18
13	Viscosity Temperature Relationships of Test Fuels	20
14	Pintle Demerits for Detroit Diesel IFBT	29
15	Pintle Demerits for Bosch APE 113 IFBT	30
16	Airflow for Detroit Diesel IFBT	30
17	Airflow for Bosch APE 113 IFBT	31
18	TDR for Detroit Diesel IFBT	31
19	TDR for Bosch APE 113 IFBT	32
20	DMD for Detroit Diesel IFBT	32
21	DMD for Bosch APE 113 IFBT	33

LIST OF TABLES

Table		Page
1	Composition and Properties of Test Fuel Blends	4
2	Engine Specifications for the DD 6V-53T Engine	6
3	Engine Specifications for the Continental LDT-465-1C Engine	6
4	Engine Specifications for the Cummins NHC-250 Engine	6
5	Engine Specifications for the General Motors 6.2L Engine	7
6	Summary of Effect of Certain Fuel Properties on Cold Startability	19
7	Summary of Property Effects on Fuel Injection Systems	21
8	Fuel Properties	22
9	Fuels and Lubricants Used in Petter Engine Test	22
10	New Oil Properties	23
11	100-Hour Petter Engine Test Results	24
12	Fuel Properties	26
13	Detroit Diesel IFBT Operating Conditions and Test Results	27
14	CLR-D Bosch APE 113 IFBT Operating Conditions and Test Results	28
15	Results of Stability Tests Compared to IFBT Pintle Deposits	34
16	Properties of Marine Fuel Oil Sample	35
17	Test Fuel Blend	36
18	Detroit Diesel IFBT Operating Conditions and Test Results	37
19	CLR-D Bosch APE 113 IFBT Operating Conditions and Test Results	38

I. INTRODUCTION

Within the Army Mobility Fuels Research and Development Program, there are concerns with development of more fuel-tolerant engines (a long-term goal), and improved fuels' availability (a short-term goal). The specific tasks covered within this activity are to (1) determine engine performance parameters, (2) define fuels' influence on engine operations, and (3) define engine-fuel operating limits. One of the major program goals is to improve the capability for using commercially available fuels and fuel substitutes without significant impairment of mission requirements. Within the plan, specific goals were requested in three general areas of mobility fuels technology: (1) Broaden Specifications, (2) Alternative Sources, and (3) Fuel Tolerance of Current Equipment. One specific goal within the area of Broaden Specifications is the development of interim specifications for variable-quality ground fuels.(1,2)*

The government currently has a variable quality fuel specification, with the properties being varied based on the expected low temperature in the region. For higher ambient temperatures, the DF-2 property levels are used, while for colder locations, the DF-1 or DF-A limits are applied. Furthermore, outside of CONUS, the above property limitations are relaxed somewhat in order to increase fuel availability.

While there are times at many locations where current VV-F-800 specifications may be overly restrictive, one problem that must be taken into consideration before relaxing the procurement requirements is that of fuel stock turnover. There have been instances (3) where Army bases are procuring DF-2 during summer months, but, because of low turnover rates, the fuel is still being used during the winter with resulting problems due to high cloud point.

The work described in this report addresses the goal to develop variable quality fuel specifications through evaluation of fuels with marginal properties with respect to effects on engine performance. Under a separate phase of this project, fuels with marginal properties were investigated with respect to their effects on combustion, power, and performance. The results are discussed in a separate report.

* Underscored numbers in parentheses refer to the list of references at the end of this report.

Federal Specification VV-F-800D, Fuel Oil, Diesel (4), covers fuels suitable for use in automotive diesel and/or compression-ignition and gas turbine engines other than aircraft under all climate conditions. Three grades of diesel fuel are described:

DF-A	Arctic Grade
DF-1	Winter Grade
DF-2	Regular Grade

The regular grade, DF-2, is classified further into standard and NATO F-54. The properties of these grades of fuel are limited by the specification to test values that will ensure good handling and satisfactory engine performance.

The bulk of the diesel fuel procured by the U.S. Government for use in CONUS is the regular grade DF-2. When the fuels meet the specification requirements, they perform satisfactorily in the equipment in which they are used. Frequently, fuels meeting all the requirements of DF-2 cannot be supplied, and petroleum companies have been requesting waivers on certain properties before bids are submitted. This occurrence is largely a result of the lesser quality of crude oils available for refining into fuels and the necessity for blending into finished fuel stocks from cracking and recycling processes.

Most of the fuels that fail to meet every specification requirement and are granted waivers are still expected to give satisfactory performance with little or no penalty. The degree of property relaxation that can be allowed without severely jeopardizing engine operation is not known. This project is intended to provide data on which variation allowance of fuel properties can be based without jeopardizing performance.

A general definition for variable quality fuels is fuels procured against relaxed specification limits.

II. OBJECTIVES

A need existed to investigate the effect of varying fuel properties on engine performance and to determine the conditions under which fuel property limits can be relaxed with little or no engine performance degradation or reduction of vehicle mission

readiness. The objectives of this program are to determine the specification properties of diesel fuel that can be varied or relaxed with little or no engine performance or handling penalties and to provide a basis for the development of interim specifications for variable-quality ground fuels.

A cross section of Army vehicles/equipment was used to evaluate effects of different fuel property variations. Test fuels were blended to emphasize specific property/equipment concerns. Test fuels and equipment are described in the respective report sections.

III. APPROACH

Possible variation in limits for the properties listed were investigated as outlined.

Cetane Number and Viscosity - Cetane number and viscosity affect startability probably more than any other performance parameters. Therefore, a matrix of test fuels with varying cetane numbers and viscosities was used in cold starting tests with four military engines. Under a separate phase, the effects of front end volatility and viscosity on the performance of three fuel injection systems were investigated.

90-Percent Distillation and End Point - Fuels with high 90-percent and end-point distillation temperatures tend to cause carbonaceous engine deposits and crankcase oil dilution. Therefore, fuel blends having 90-percent distillation and end-point temperatures above the DF-2 specification limits were evaluated in 100-hour Petter engine tests for deposit-forming tendencies and crankcase dilution.

Accelerated Stability - With respect to engine performance, it is anticipated that fuels with poor accelerated stability test results may produce deposits in fuel injector systems, resulting in plugged injectors. As a result, fuels with accelerated stability values above the limit specified in VV-F-800D were evaluated in an injector fouling bench test.

Carbon Residue - Fuels with high carbon residue may form harmful deposits in the combustor of a gas turbine engine and in the fuel injectors of a diesel engine. In both situations, the combustion process may be disrupted. Thus, a fuel with carbon residue value above the limit shown in VV-F-800D was evaluated in an injector fouling bench test.

IV. EXPERIMENTAL AND DISCUSSION OF RESULTS

A. Cetane Number and Viscosity

The effects of cetane number and viscosity on the low-temperature startability of four military engines were evaluated using a test matrix of six fuels described in TABLE 1. Two fuel sets of three fuels each were blended. Both sets had fuels with cetane numbers of approximately 40, 35, and 30; and the viscosities at 40°C for one set were about 1.0 cSt, and 5 to 6 cSt for the other set. To provide the desired properties for each blend, several fuels and special refinery products were used. These products included a

TABLE 1. Composition and Properties of Test Fuel Blends
(10-Gallon Batches)

Blend No. / AL-Code No.	A40 14010	A35 14011	A30 14012	B40 14013	B35 14014	B30 14015
Composition, vol%						
Kerosene	81	69	62	--	--	--
Xylene Tower Bottoms	19	31	38	--	--	--
Burner No. 2	--	--	--	28	--	50
Telura® 126	--	--	--	--	--	50
Telura® 309	--	--	--	72	--	--
Telura® 705	--	--	--	--	82	--
Cat 1H2/1G2	--	--	--	--	18	--
Properties						
K. Vis. at 40°C, cSt, D 445	1.13	1.03	0.99	5.90	5.20	5.69
K. Vis. at 0°C, cSt, D 445	2.12	2.15	1.85	24.0	24.2	25.5
Cetane No., D 613	38.9	33.3	30.2	41.1	34.8	31.8
Gravity, °API, D 1298	43.6	40.7	39.9	27.9	40.1	22.6
Distillation, °F(°C), D 86						
IBP	305(152)	313(156)	307(153)	341(172)	472(244)	350(177)
10% recovered	342(172)	335(168)	332(167)	479(248)	504(262)	417(214)
50% recovered	379(193)	364(184)	359(182)	594(312)	526(274)	600(316)
90% recovered	421(216)	416(213)	414(212)	652(344)	564(296)	694(368)
EP	445(259)	450(232)	454(234)	700(371)	616(324)	760(404)
Carbon, mass%, D 3178	86.06	86.85	86.97	87.21	85.71	87.06
Hydrogen, mass%, D 3178	13.27	12.62	12.28	12.71	14.24	11.58
Sulfur, mass%, D 2622	0.01	0.01	0.01	0.31	0.09	0.84
Net Heat Comb., D 240 Btu/lb	18,373	18,127	18,111	18,122	18,587	17,808

kerosene, a reference DF-2 fuel known as Cat 1H2/1G2, a No. 2 burner fuel, xylene tower bottoms, and special products described as industrial process oils as follows: Telura® 126 is a high-aromatic (67 mass%), high-viscosity (24 cSt at 40°C) fraction; Telura® 309 is a naphthenic, intermediate viscosity (0.1 cSt at 40°C) fraction; and Telura® 705 is a nonaromatic (1.0 mass% aromatics), intermediate viscosity (6.1 cSt at 40°C) fraction.

1. Cold-Start Engine Tests

The four engines investigated in this program were the Detroit Diesel 6V-53T, the Continental LDT-465-1C, the Cummins NHC-250, and the GM 6.2L. Specifications for these engines are listed in TABLES 2, 3, 4, and 5, respectively. For cold-start evaluations using the fuels described in TABLE 1, each engine was installed in a cold room capable of being chilled to -40°C (-40°F). The engines were not coupled to a dynamometer or any other power absorption device.

The normal engine-mounted fuel lines and pumps supplied with the engines were used. If primary and secondary fuel filters were standard equipment, the primary filter was removed, and only the secondary was used to increase flushing efficiency between fuels. The fuel supply was provided from a vented 1-gallon container, resting on a fuel scale located inside the cold room. The fuel supply line and return line from the engine were routed so they did not touch the container.

The normal lubricating oil systems for each engine were used in these tests. The lubricant used was a 15W-40 grade, MIL-L-2104D reference oil, qualification number MC 231.

The standard 24-volt starting motors supplied with the engines were used for these evaluations. The batteries were maintained fully charged and located externally to the cold room. Minimum length cables were used to supply voltage to the starter in order to avoid voltage drops in the lines. An external manually operated starter switch was provided. This switch was a momentary contact type, which energized the starter when depressed and de-energized it when released.

TABLE 2. Engine Specifications for the DD 6V-53T Engine

Model:	5063-5395
Engine Type:	Two-Cycle, Compression Ignition, Direct Injection, Turbo-Supercharged
Starting Aids:	Air Box Heater
Cylinders:	6, V Configuration
Displacement:	5.21L (318 cubic inches)
Bore:	9.8 cm (3.875 inches)
Stroke:	11.4 cm (4.5 inches)
Compression Ratio:	18.7:1
Injection Pump Type:	DD N 70 Unit Injectors
Maximum Rated Power:	224 kW (300 BHP) at 2800 rpm
Maximum Rated Torque:	858 NM (633 lb-ft) at 2200 rpm

TABLE 3. Engine Specifications for the Continental LDT-465-1C Engine

Model:	LDT-465-1C
Engine Type:	Four-cycle, Compression Ignition, M.A.N. Combustion System, Turbocharged
Starting Aids:	Manifold Heater
Cylinders:	6, Inline
Displacement:	7.83 (478 cubic inches)
Bore:	11.58 cm (4.56 inches)
Stroke:	12.37 cm (4.87 inches)
Compression Ratio:	22:1
Fuel Injection:	Bosch Rotary Distributor w/Density Compensation
Rated Power:	145-156 kW (194-209 BHP) at 2800 rpm
Rated Torque:	597 NM (429 lb-ft) at 2000 rpm

TABLE 4. Engine Specifications for the Cummins NHC-250 Engine

Model:	Cummins NHC-250
Engine Type:	Normally Aspirated, Direct Injection
Starting Aids:	Manifold Heater (Glow Plug and Spray Nozzle)
Cylinders:	6 Cylinder; 4 Cycle; Inline
Displacement:	14.01 L (855 cubic inches)
Bore:	14.97 cm (5.5 inches)
Stroke:	15.24 cm (6 inches)
Compression Ratio:	15.8:1
Fuel Injection:	Cummins PT Fuel Pump and Injectors
Rated Power:	179.5 kW (240 BHP) at 2100 rpm
Rated Torque:	892 NM (658 lb-ft) at 1500 rpm

TABLE 5. Engine Specifications for the General Motors 6.2L Engine

Model:	GM 6.2L
Engine Type:	Four-Cylinder, Compression Ignition, Ricardo Comet V Combustion Chamber
Starting Aids:	Glow Plug
Cylinders:	8, V-Configuration
Displacement:	6.217 L (379 cubic inches)
Bore:	10.1 cm (3.98 inches)
Stroke:	9.7 cm (3.82 inches)
Compression Ratio:	21.3:1
Fuel Injection:	Stanadyne DB-2 Fuel Injection Pump, Bosch Pintle Injectors
Rated Power:	116 kW (155 BHP) at 3600 rpm
Rated Torque:	355 NM (262 lb-ft) at 2200 rpm

Instrumentation was provided to measure the following parameters:

Fuel Consumption - Fuel consumption was measured using the 1-gallon container and scale arrangement described earlier. The fuel scale was capable of measuring in the 0 to 10 kg range with a resolution of 0.05 kg. A readout for the weight of the fuel and container was provided on the control panel.

Engine Speed - Engine speed (rpm) was measured with an electronic speed sensor that had a resolution of 10 rpm. A digital readout and a chart recorder were provided for rpm measurements.

Temperatures - Temperatures were measured using Type J thermocouples with a readout device on the control panel at the following locations:

- Inlet air stream. Air box temperature for the DD 6V-53T engine, intake manifold temperature for the other engines.
- Cooling water inlet
- Oil sump
- Fuel in supply container
- Exhaust
- Air in cold room

More detail of preparation and completion of each test are described in Appendix A.

a. Cold Starting With the DD 6V-53T Engine

The cold start test procedure for the DD 6V-53T engine was patterned after the one found in technical manual TM 9-2350-230-10.(5) At temperatures below 4.4°C (40°F), an air box heater is used as a starting aid. The starter button was depressed for 20 seconds, and at the same time, the air box heater switch was engaged for 1 second and released for 2 seconds. If no start occurred, the starter and heater button were released for 20 seconds, and the process was repeated until the engine started, or 20 seconds elapsed. The sequence was repeated for a total of 120 seconds cranking time. If the engine did not start in that time frame, the test was recorded as "no start." An unaided starting procedure similar to this was used in previous work with a DDA 4-53T engine.(6)

b. Cold Starting With the Continental LDT-465-1C Engine

The procedure for starting the LDT-465-1C engine was patterned after the one found in TM 9-2320-209-10 (7) and was similar to that used with the 6V-53T engine. The temperature below which the starting aid was used was -7°C (20°F). A manifold heater is used in this engine as the starting aid. Again if the engine did not start within 120 seconds cranking time, the test was recorded as "no start."

c. Cold Starting With the Cummins NHC-250 Engine

TM 9-2320-260-10-1, the tech manual for the 5-ton 6x6 M809 series trucks with the Cummins NHC-250 engine, describes the procedure for starting this engine at temperatures below 0°C (32°F).(8) This procedure was adapted for this test engine as follows: The manifold heater switch was engaged. After 15 seconds, the primer pump was activated and immediately the starter button was depressed and held. The primer pump was released for 2 seconds and engaged again for 2 seconds. If no start occurred, the sequence was repeated for 10 seconds and all buttons were released for 10 seconds. The process was then repeated until the engine started, or for a total of 120 seconds cranking time. As with the two previous engines, if no start occurred within 120 seconds cranking time, the test was recorded as "no start."

d. Cold Starting With the General Motors 6.2L Engine

The GM 6.2L engine has a glow plug installed in the manifold that is activated when the ignition switch is turned on. The switch also illuminates a "wait to start" light that goes out when the glow plug is sufficiently hot for the starter to be engaged. The net effect is that the glow plug is a starting aid that operates at all ambient temperatures. However, when the temperature is below 0°C (32°F), special procedures adapted for these tests are to be used.(9) The ignition switch was turned on, and after the "wait to start" light went out, the fuel pump was engaged and the starter button depressed. If the engine did not start in 15 seconds, the pump and starter were released for 15 seconds before attempting to start again. If no start occurred, the sequence was repeated for a maximum of 90 seconds cranking time, and, at the end of this period, the test was recorded as "no start."

2. Cold-Start Test Results

a. DD 6V-53T Engine

The data for all the cold-start tests conducted with the DD 6V-53T engine are shown in TABLE B-1 of Appendix B. The first seven tests were conducted with a referee grade diesel fuel meeting the requirements of Military Specification MIL-F-46162B (10) to establish a baseline for these tests. The effects of cetane number and viscosity on the starting times for the "40" cetane number test fuels at low temperatures are shown in Fig. 1. Blend A40 produced starts at 7°C oil sump temperature without the starting aid and at 0°C and -2°C with the starting aid. The DD 6V-53T engine started readily on Blend B40, the higher viscosity fuel, at 3°C without starting aid and at -2°C with aid. The higher viscosity fuel gave quicker starts in these tests.

Fig. 2 is a plot of the test data for blends A35 and B35. At approximately 6°C oil sump temperature, five starts were attempted on blend A35, without use of the air box heater. Three tests resulted in "no starts," and two tests gave starts after 80 and 100 seconds. No starts occurred at 3°C without the air box heater or at 0°C with the heater engaged. The engine started readily on Blend B35 at 3°C without aid and as low as -3°C with the starting aid. At -4°C, the starting time was much longer, and no starts occurred at lower temperatures.

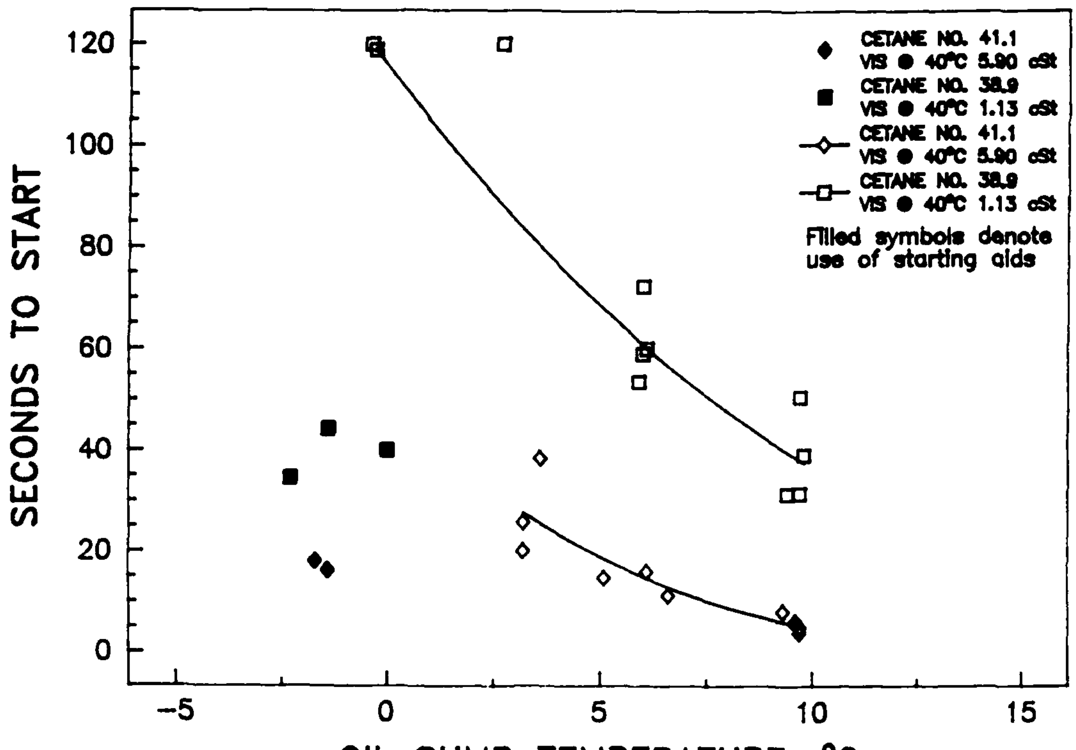

Figure 1. "40" cetane number fuels - DD 6V-53T engine
◆,◇ - B40; ■,□ - A40

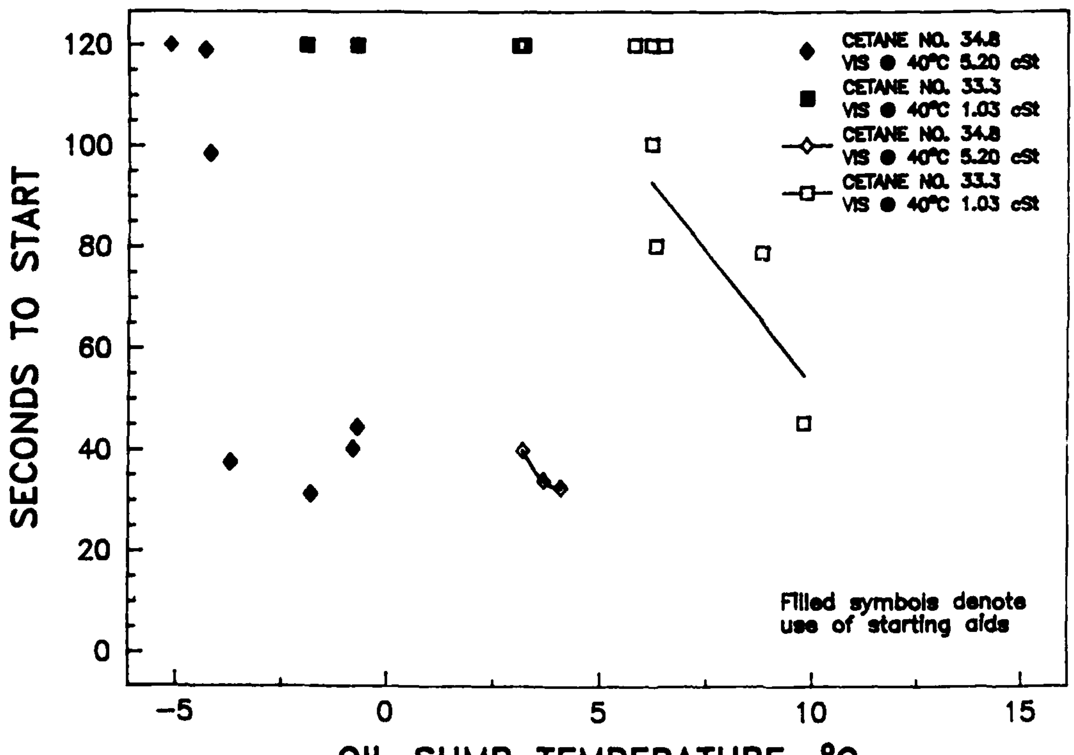

Figure 2. "35" cetane number fuels - DD 6V-53T engine
◆,◇ - B35; ■,□ - A35

Fig. 3 shows the relationships between starting time and oil sump temperatures of blends A30 and B30 in the DD 6V-53T engine. The engine would not start on Blend A30 without or with starting aid in the oil sump temperature range of 7°C down to -1°C. With Blend B30, the engine started with the oil sump temperature at 7°C but not at lower temperatures without the air box heater. With the heater on, the lowest temperature for a start to occur was 4°C. Faster starts occurred with the higher viscosity fuel.

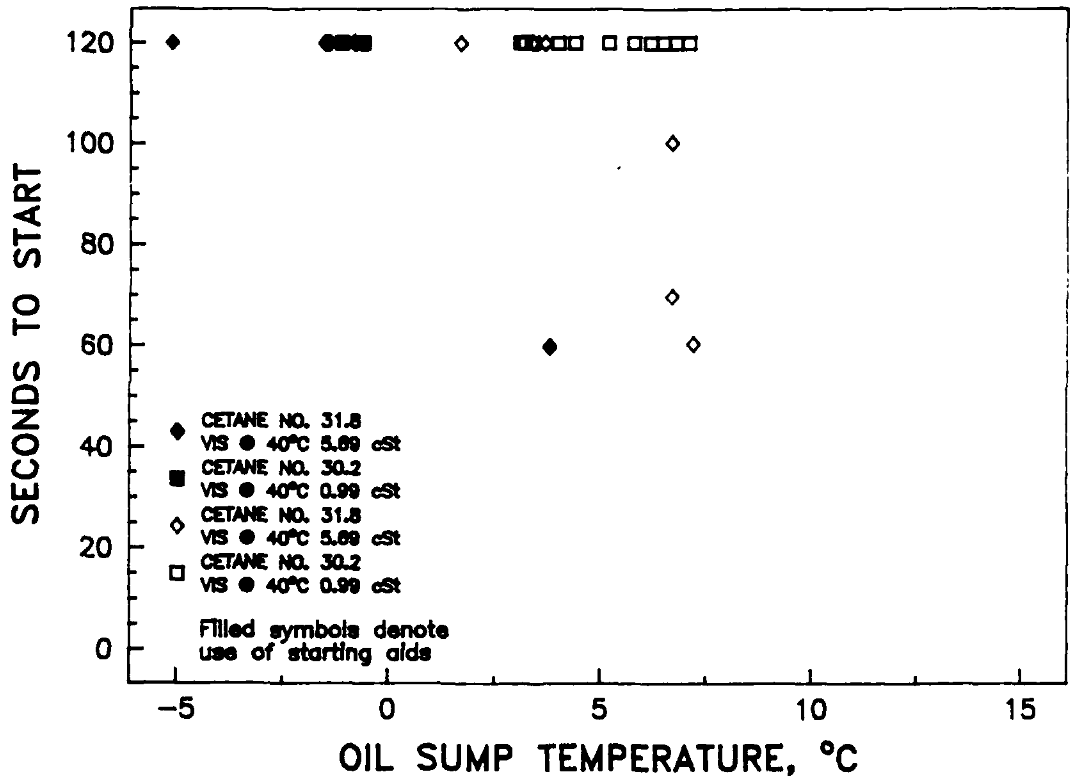

Figure 3. "30" cetane number fuels - DD 6V-53T engine
◆,◇ - B30; ■,□ - A30

The DD 6V-53T engine appears to be limited to a 40 minimum cetane number fuel to ensure starting in cold ambient temperatures. The higher viscosity fuels produced faster starts than the lower viscosity ones.

b. <u>LDT-465-1C Engine</u>

The data for the cold-start tests with the LDT-465-1C engine are presented in TABLE B-2 of Appendix B. Fig. 4 depicts the cold-start performance of the "40" cetane number test fuels in the LDT-465-1C engine. The engine started on fuel A40 with relative ease at -4°C oil sump temperature. At -7°C, with assistance, the engine was more difficult

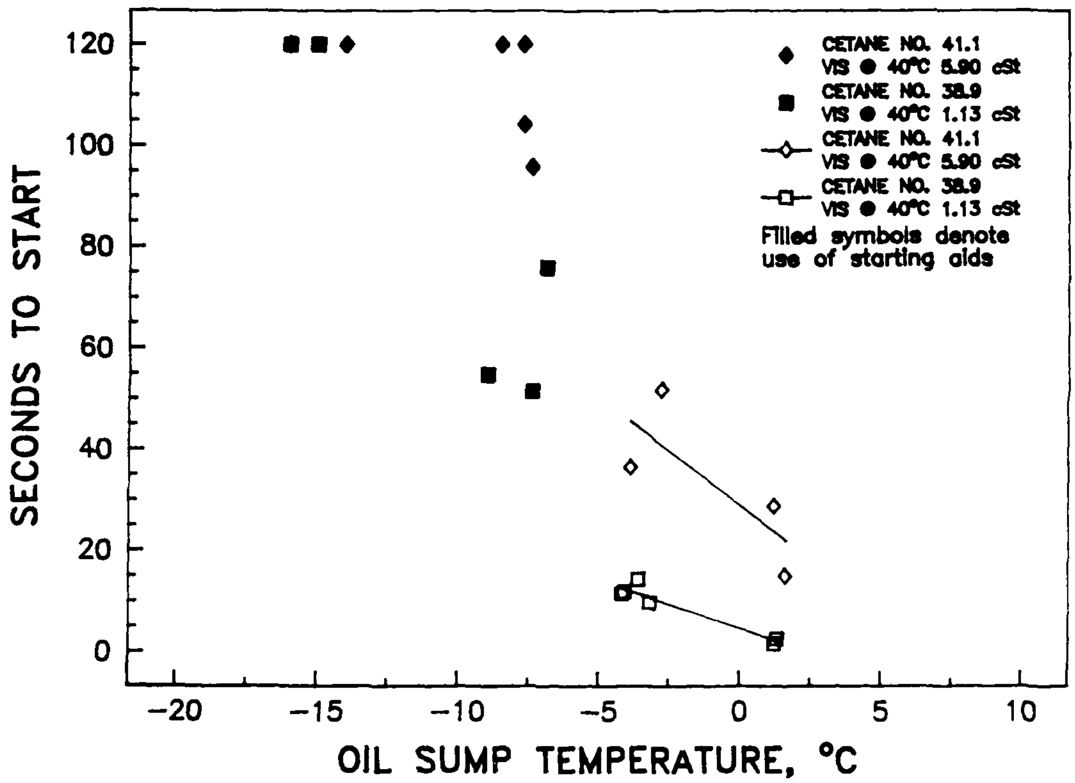

Figure 4. "40" cetane number fuels - LDT-465-1C engine
◆,◇ - B40; ■,□ -A40

to start, and at -15°C, it would not start. Similar behavior occurred with fuel B40; however, more cranking time was required for the engine to start on this fuel. At -8°C, the use of the starting aid did not result in starts in two out of four attempts.

The cold-starting characteristics of the LDT-465-1C engine on fuels A35 and B35 are shown in Fig. 5. The engine started on both fuels within 20 seconds cranking time at oil sump temperatures down to -5°C without the starting aid. At -7°C and below, utilizing the manifold heater, much longer cranking times were required for starts, and at -9°C and below no starts occurred with either fuel.

Fig. 6 shows the cold start performance of the LDT-465-1C engine on test fuels A30 and B30. With fuel A30 the engine started readily without aid at -2°C. At -8°C, with starting aid engaged, starts occurred with longer cranking times, and at -10°C and -17°C the engine did not start after 120 seconds cranking time. Starts occurred with fuel B30 at -2° to -3°C after about 80 seconds cranking time. Utilizing the manifold heater with fuel B30, no starts occurred below oil sump temperatures of -9°C.

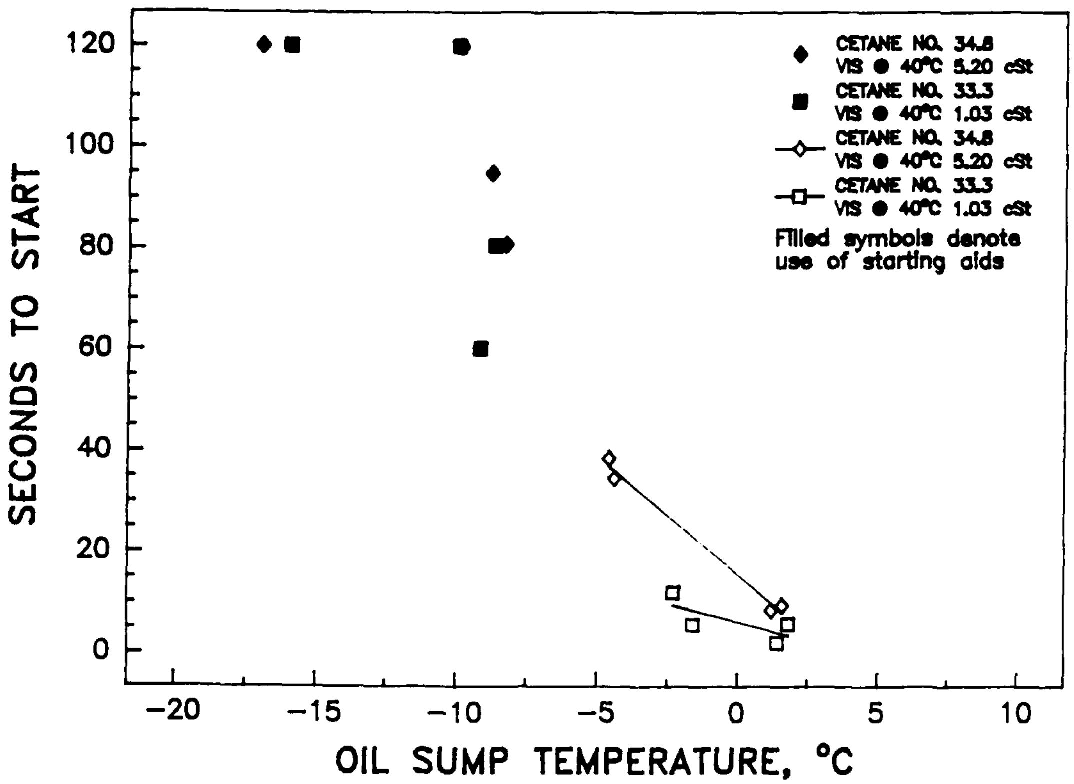

Figure 5. "35" cetane number fuels - LDT-465-1C engine
◆,◇ - B35; ■,□ -A35

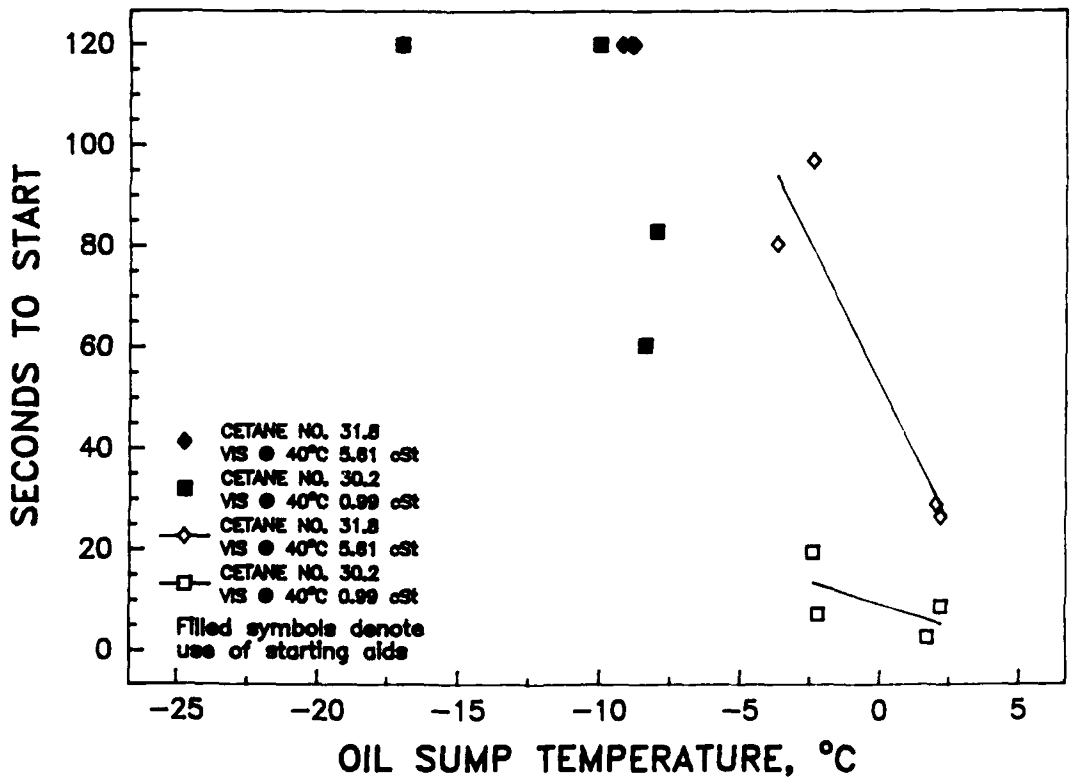

Figure 6. "30" cetane number fuels - LDT-465-1C engine
◆,◇- B30; ■,□ - A30

The data developed in this program indicates that the LDT-465-1C engine was started at lower temperatures than the DD 6V-53T engine on the same test fuels. The LDT-465-1C engine started more readily on the lower viscosity fuels.

c. NHC-250 Engine

The data developed in the cold-starting test with NHC-250 engine using the six-fuel test matrix are presented in TABLE B-3 of Appendix B.

The cold-start performance of the NHC-250 engine on fuel blends A40 and B40 is depicted in Fig. 7. With no starting aid, the engine started within 30 seconds cranking time at 2°C oil sump temperature with fuel A40 and at 5°C with fuel B40. Below 0°C, the NHC-250 engine started with assistance from the manifold heater within 40 seconds in every attempt. Oil sump temperatures were as low as -26°C. Start attempts with fuel B40 generally required longer cranking time as the temperature was lowered. At -20°C oil sump temperature the engine did not start in two attempts.

The cold-start performance of the NHC-250 engine with test fuels A35 and B35 is presented in Fig. 8. The cold-starting characteristics of the engine were very similar for both fuels. At 2° to 3°C oil sump temperatures, the engine started on both fuels within 30 seconds cranking time. With the manifold heater operating between 0° and -21°C oil sump temperature, all starts but one were successful within 30 seconds cranking time. One start at -20°C occurred with fuel A35 after 86 seconds cranking time.

Fig. 9 depicts the cold startability of the NHC-250 engine with the "30" cetane fuels A30 and B30. Longer cranking time was required for starts with "30" cetane fuels and at 2°C oil sump temperature, the engine did not start on fuel B30. With the starting aid, the NHC-250 engine started on fuel A30 within 32 seconds at -24°C. With fuel B30 the engine was more difficult to start, and at -24°C the engine did not start after 120 seconds cranking time.

The Cummins NHC-250 engine started readily at low temperatures, with low cetane number fuels. It was observed that the higher viscosity fuels appear to hinder the starting of the NHC-250 engine at low temperatures. It is surmised that at these low temperatures, the fuel viscosity become so high that the fuel pump can not handle it properly.

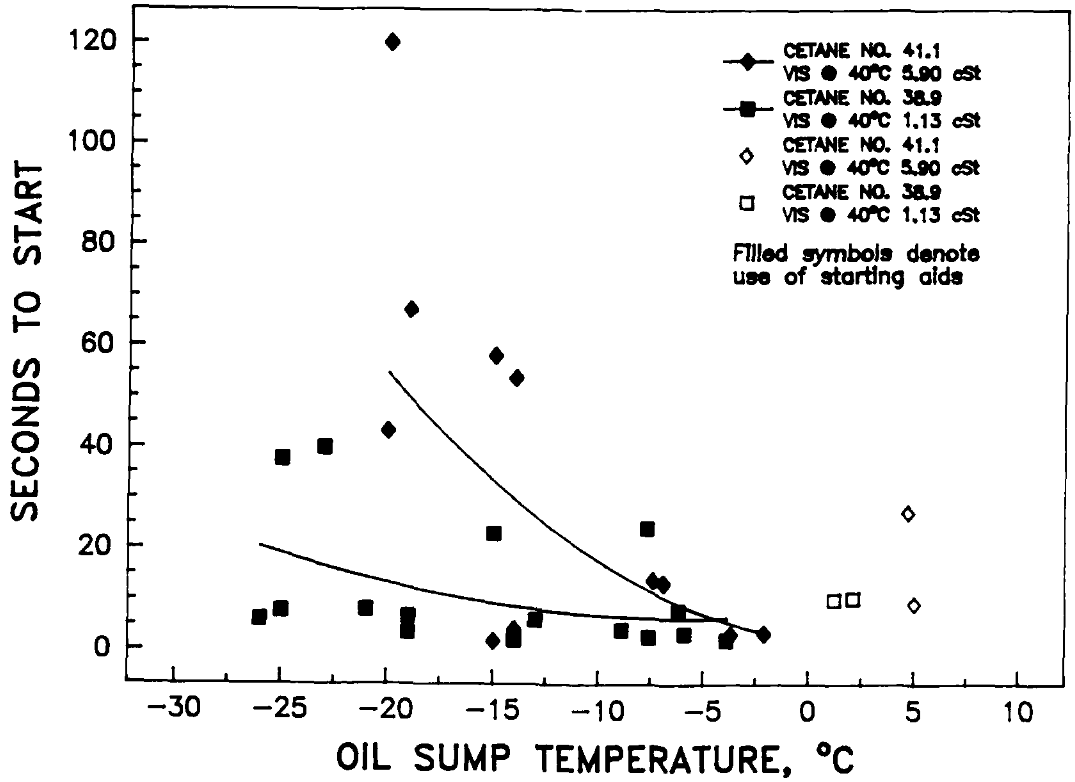

Figure 7. "40" cetane number fuels - NHC-250 engine
◆,◇ - B40; ■,□ - A40

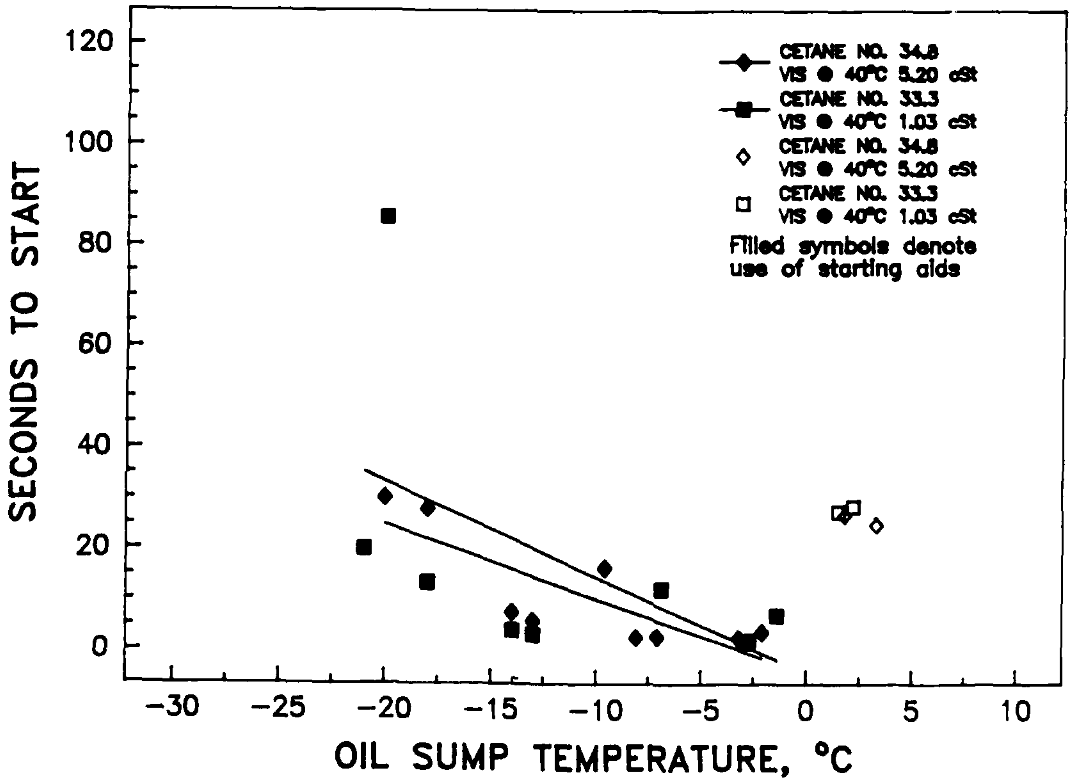

Figure 8. "35" cetane number fuels - NHC-250 engine
◆,◇ - B35; ■,□ - A35

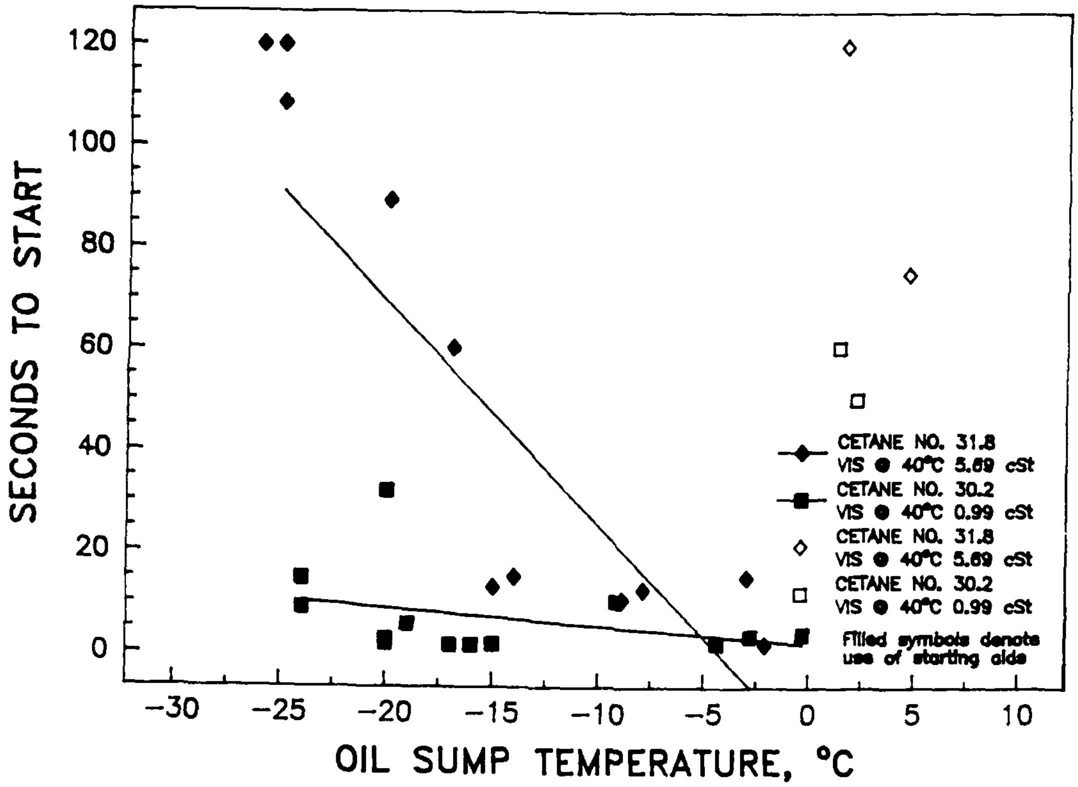

Figure 9. "30" cetane number fuels - NHC-250 engine
◆,◇ - B30; ■,□ - A30

d. GM 6.2L Engine

The data for the cold-start tests with the GM 6.2L engine are presented in Table B-4 of Appendix B.

Fig. 10 shows the cold-start performance of the 6.2L engine on test fuels A40 and B40. The engine started on fuel A40 within 12 seconds cranking time with the oil sump temperature at -22°C. At -29°C, the engine did not start after 90 seconds of cranking time. With fuel B40 the 6.2L engine started about 0°C oil sump temperature, but below that temperature, no starts occurred. The Detroit Diesel Allison Division of General Motors has indicated that the Stanadyne fuel injection pump used in the 6.2L engine is designed to handle fuel with a maximum viscosity of 20 cSt.(11) It appears that this fuel, and the other high viscosity fuels in the test matrix, exceed this viscosity at the cold temperatures in this program.

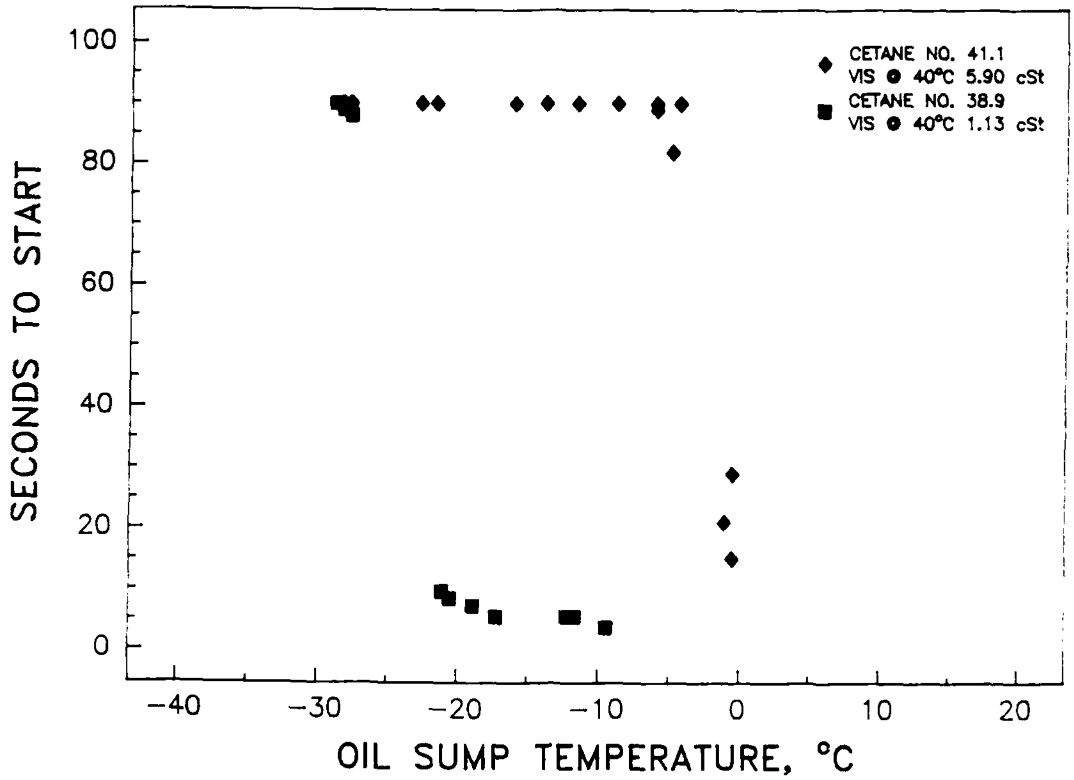

Figure 10. "40" cetane number fuels - GM 6.2L engine
◆- B40; ■ - A40

The cold-starting performance of the 6.2L engine on test fuels A35 and B35 is depicted in Fig. 11. The engine started on fuel A35 within 30 seconds cranking time at oil sump temperatures as low as -23°C. The engine did not start after 90 seconds at -25°C and at -29°C. With fuel B35 the engine started at 0°C within 20 seconds and at -2° to -3°C within 50 seconds in several attempts. Two tests at 0° and -6°C resulted in starts after 88 and 89 seconds cranking time, respectively. At -10°C, the engine did not start.

The cold-start tests with the 6.2L engine using fuels A30 and B30 are plotted in Fig. 12. Starts were obtained with fuel A30 within 30 seconds cranking time at -21°C oil sump temperatures. Two starts occurred at -20°C after 60 seconds cranking time, and four no-starts were observed at -19° down to -20°C. The higher viscosity fuel B30 gave scattered results. Several successful starts occurred between 4° and 16°C within 20 seconds cranking time. Between 0° and 8°C, there were starts in less than 20 seconds, some in 50 to 60 seconds and three "no starts."

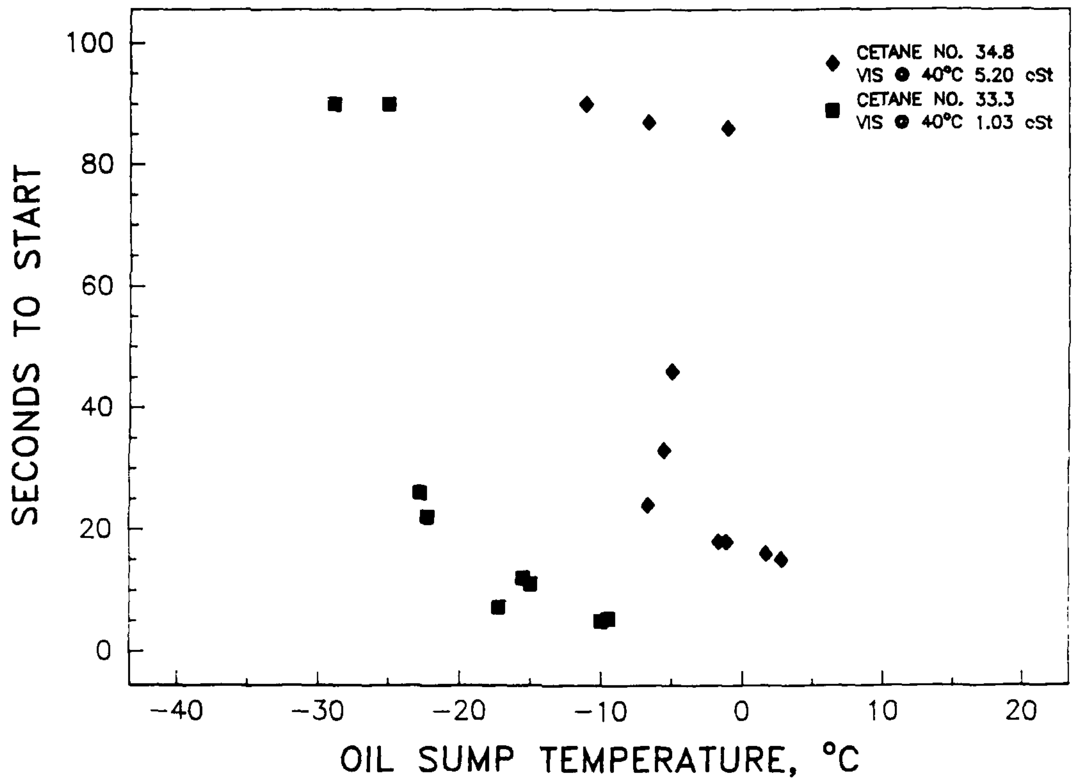

Figure 11. "35" cetane number fuels - GM 6.2L engine
◆- B35, ■- A35

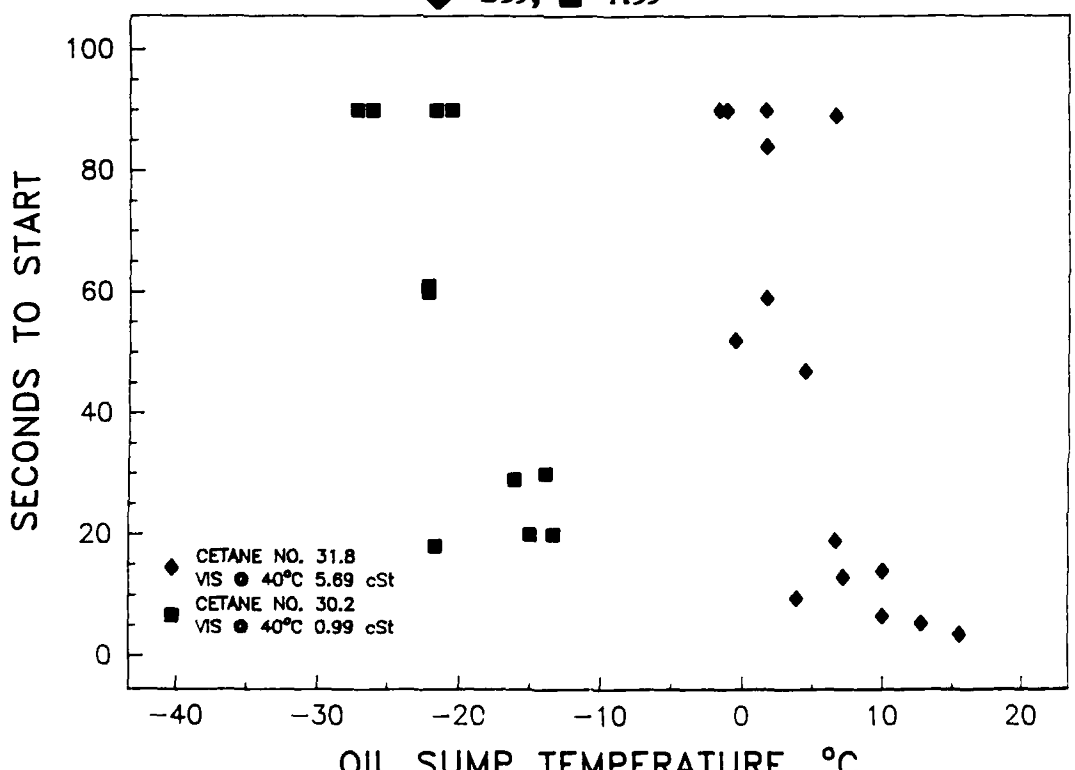

Figure 12. "30" cetane number fuels - GM 6.2L engine
◆- B30; ■- A30

The results of the evaluation of the GM 6.2L engine indicate that this engine appears to be more limited by viscosity for cold starting than by cetane number. However, with the A30 fuel, the engine failed to start at a higher temperature than with the higher cetane number, low viscosity fuels. The implication is that adequate cetane numbers are also important for cold startability of the GM 6.2L engine.

The viscosities of the test fuels were measured at 40° and 0°C as shown in TABLE 1. The values at 0°C for fuels B40, B35 and B30 are above the 20-cSt limit stated by Detroit Diesel Allison Division for the Stanadyne fuel injection pump used in the GM 6.2L engine. When these viscosity values are plotted on ASTM Standard Viscosity-Temperature Chart, Fig. 13, it appears that all three fuels have a kinematic viscosity of 20 cSt at about 4°C. The cold-start attempts with the 6.2L engine using these high viscosity fuels were erratic at oil sump temperatures of 0°C and below. TABLE 6 summarizes the results of the cold-starting evaluations showing effects of some selected fuel properties on cold startability.

TABLE 6. Summary of Effect of Certain Fuel Properties on Cold Startability

Engine	Cetane Number	Lowest Starting Temperature, °C	K. Vis. at 40°C, cSt
Detroit Diesel 6V-53T	38.9	0	1.13
	34.8	-3	5.20
Continental LDT-465-1C	30.2	-8	0.99
	34.8	-9	5.20
Cummins NHC-250	30.2	-24	0.99
	31.8	-20	5.69
GM 6.2L	30.2	-21	0.99
	31.8	0	5.67

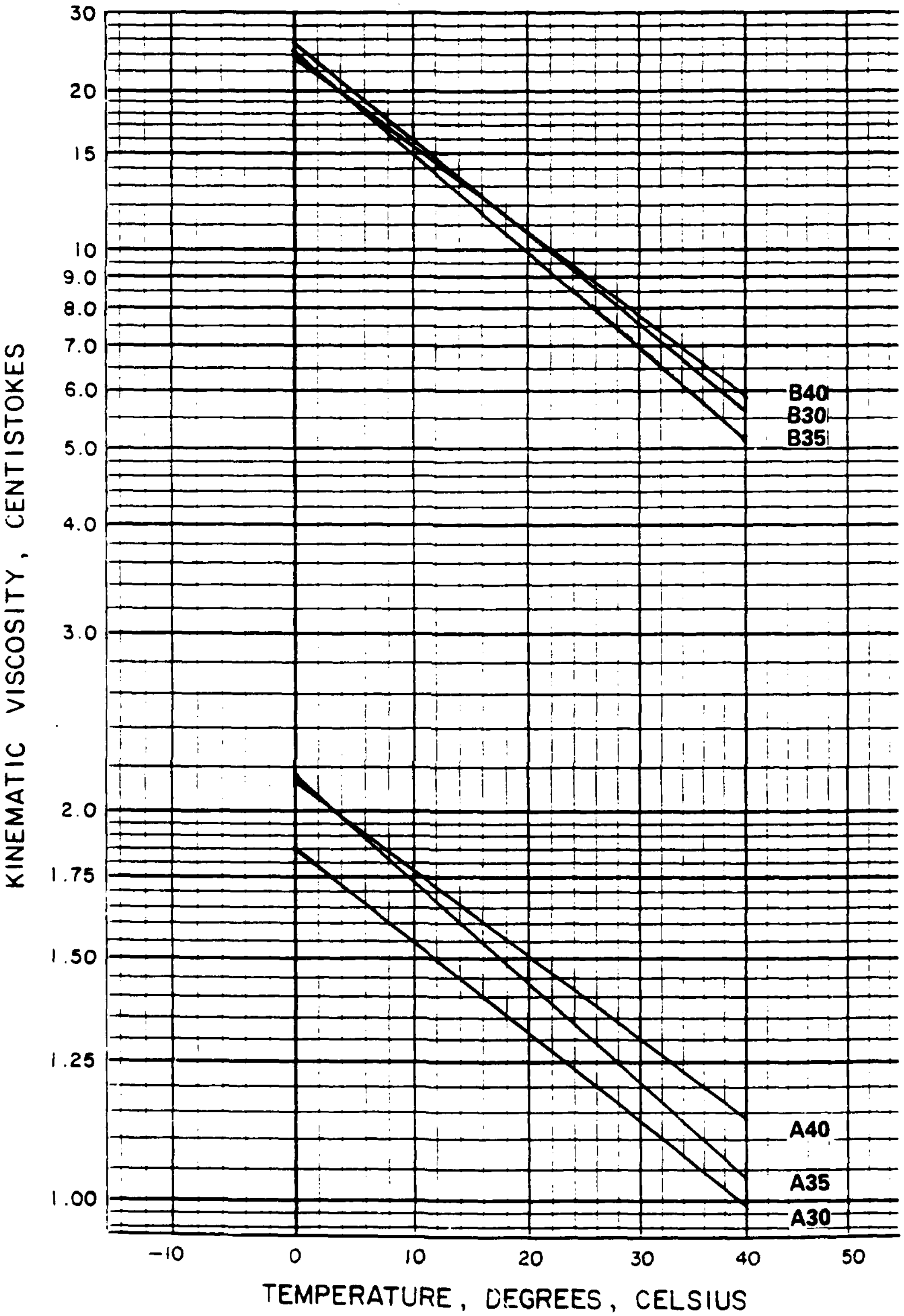

Figure 13. Viscosity temperature relationships of test fuels

3. Effect of Front-End Volatility and Viscosity on Fuel Injection Systems

Under a separate phase, three different fuel injection systems from three classes of engines represented by the Continental LDT-465-1A, the Cummins NHC-250, and the Detroit Diesel 6V-53T, were evaluated on three fuels for front-end volatility and viscosity effects. The test fuels were a JP-4 (kinematic viscosity at 40°C = 0.64 cSt, 68°C at 10-percent recovered), DF-2 (kinematic viscosity at 40°C = 2.89 cSt, 207°C at 10-percent recovered), and an industrial solvent Telura® 323 (kinematic viscosity at 40°C = 21.4 cSt, 331°C at 10-percent recovered). This work was reported in "Evaluation of Three Military Diesel Injection Systems on Alternative Fuels," Interim Report BFLRF No. 214.(12) The results showed that there was no evidence of vapor lock due to front-end volatility effects at high test temperatures for any of the injection systems tested. Viscosity was observed to affect the fuel flow rate. For the LDT-465-1A and 6V-53T injection systems, fuels with relatively low viscosities tended to leak past the barrel and plunger assemblies, resulting in a decreased fuel flow rate. Leakage did not appear to be a problem with the NHC-250 injection system. The fuels with higher viscosities tended to have problems completely filling the pump in the time available, resulting also in decreased fuel flow.

In TABLE 7, the effects of front-end volatility and viscosity on the injection systems of three military engines are summarized.

TABLE 7. Summary of Property Effects on Fuel Injection Systems

Engine/Injection System	Front-End Volatility	Viscosity
Continental LDT-465-1A	No vapor lock	Low - leaked High -no pump filling
Cummins NHC-250	No vapor lock	Low - no leakage High - no pump filling
Detroit Diesel 6V-53T	No vapor lock	Low - leaked High - no pump filling

B. 90-Percent Distillation and End Point

Fuels with 90-percent distillation and final boiling point temperatures above the current limits for DF-2 fuels were evaluated for performance in a Petter model PH1W single-cylinder diesel engine. A reference DF-2 (Cat 1H2/1G2), an experimental referee grade Type II, and a special fuel blend with high distillation temperatures, whose properties are shown in TABLE 8, were the fuels selected for this program. Six 100-hour tests listed in TABLE 9 under controlled conditions were conducted with these two fuels and selected lubricants.

TABLE 8. Fuel Properties

Properties	ASTM Test Method	AL-14823-F Cat 1H2/1G2	AL-14751-F Type II	AL-15515-F Special Blend
Gravity, °API	D 1298	34.5	24.8	32.7
Density, kg/L at 15°C	D 1298	0.8520	0.9048	0.8613
Sulfur, wt%	D 2622	0.42	0.92	0.28
K. Vis. at 40°C, cSt	D 445	3.11	7.0	7.07
Carbon residue on 10% bottoms, wt%	D 524	0.10	0.15	0.18
Distillation, °C	D 86			
IBP		210	196	187
10% recovered		240	241	282
50% recovered		272	314	328
90% recovered		324	385	383
95% recovered		341	404	404
EP		350	404	404

TABLE 9. Fuels and Lubricants Used in Petter Engine Test

Test	Fuel	Lubricant
1-JB	Cat 1H2/1G2	MIL-L-2104D
2-JB	Type II	MIL-L-2104D
3-JB	Type II	95-cSt Oil
4-JB	Cat 1H2/1G2	95-cSt Oil
5-JB	High Boiling	100 Neutral
6-JB	Cat 1H2/1G2	100 Neutral

The lubricating oil used in Tests 1-JB and 2-JB was MIL-L-2104D (13), 30-grade reference oil, a fully compounded oil containing a high level of dispersant-detergent additive. The oil used in Tests 3-JB and 4-JB was a 95-cSt hydraulic oil that contained an oxidation inhibitor. The lubricant in tests 5-JB and 6-JB was a 100 neutral basestock with no additives. The new oil properties are shown in TABLE 10.

TABLE 10. New Oil Properties

Lubricant	Test Method	MIL-L-2104D AL-14726-L	Hydraulic Oil AL-15201-L	100 Neutral AL-15709-L
K. Vis. at 40°C, cSt	D 445	95.8	95.2	20.04
K. Vis. at 100°C, cSt	D 445	11.1	10.7	4.00
Viscosity Index	D 2270	101	95	92
Total Acid No., mg KOH/g	D 664	2.6	0.75	0.01
Total Base No., mg KOH/g	D 664	7.4	0.25	0.10

The data for the six tests conducted in this phase are shown in TABLE 11. Tests 1-JB and 2-JB, which used the MIL-L-2104D lubricant, resulted in very clean engine parts attributed to the detergency in the oil. Engine wear based on used oil iron content was very similar for both tests. The use of high sulfur fuel in test 2-JB resulted in a slightly lower used oil total base number. Unexplained high used oil copper content was observed in test 1-JB. Tests 3-JB and 4-JB, using the nondispersant oil, showed differences that could be due to the different fuels. As indicated by the higher iron content of the used oil, Test 3-JB with the Type II fuel showed more wear than Test 4-JB using the Cat 1H2/1G2 fuel. This difference could be due to the higher sulfur content of the Type II fuel. Test 5-JB, with the high boiling fuel and 100 neutral lubricant, showed a higher level of wear (based on the iron content in the used oil) and measured ring wear than Test 6-JB with Cat 1H2/1G2 fuel and 100 neutral lubricant. The piston weighted total demerits (WTD) rating was slightly worse with the Cat 1H2/1G2 fuel. Although the lubricant thickened considerably in all the tests, it was proportionally more pronounced with the 100 neutral, which had no additives present.

The high boiling fuel may have caused a higher wear rate in Test 5-JB; however, the evidence is not conclusive. The data obtained in this series of tests with the Petter

TABLE 11. 100-Hour Petter Engine Test Results

Test No. Fuel	1-JB Cat 1H2/1G2	2-JB Type II	3-JB Type II	4-JB Cat 1H2/1G2	5-JB High Boiling	6-JB Cat 1H2/1G2
Used Oil Properties						
K. Vis., 40°C, cSt	104.01	119.25	149.61	153.35	48.03	92.72
K. Vis., 100°C, cSt	13.01	15.46	25.42	26.93	17.85	37.82
TAN, mg KOH/g, D 664	3.67	3.91	1.93	1.33	0.74	0.92
TBN, mg KOH/g, D 664	6.09	4.66	0.01	0.22	0.07	0.01
Pentane Insolubles "A", %	0.21	0.59	3.59	3.25	3.80	5.15
Toluene Insolubles "A", %	0.18	0.55	3.38	3.08	3.63	5.03
Pentane Insolubles "B", %	2.90	4.55	3.52	3.18	3.76	5.13
Toluene Insolubles "B", %	2.73	4.31	3.30	2.99	3.49	4.91
Fuel Dilution, %	1.0	0.5	0.2	0.8	0.09	0.95
Metals, XRF						
Fe, ppm	82	65	233	90	480	230
Cu, ppm	150	< 10	<10	< 10	< 10	< 10
Cr, ppm	<15	< 15	<15	< 15	40	< 10
Pb, ppm	<60	< 60	<60	< 60	< 60	< 60
S, %	0.56	0.58	0.40	0.35	0.10	0.11
ICP, Elements, ppm						
Fe	101	79	261	86	491	208
Cr	1	1	1	3	31	25
Cu	203	13	12	8	8	9
Si	14	6	17	6	8	5
Pb	28	1	2	< 1	< 1	< 1
Zn	1485	1592	353	346	14	9
P	1269	1276	420	331	125	31
Mg	1715	1854	11	3	4	2
Piston WTD Rating	19.6	18.8	135.2	149.1	142.2	162.6
Ring End Gap, in.	0.003	0.001	0.005	0.003	0.012	0.003
Ring Side Clearance, in.	0.001	0.001	0.000	0.000	0.000	0.000
Liner Avg. Wear, in.	0.0007	0.0001	0.0002	0.0003	0.0001	0.0002
Lubricant	— MIL-L-2104D — Grade 30	Grade 30	Hydraulic Oil	Hydraulic Oil	100 Neutral	100 Neutral
Oil Sump Temp., °F (°C)	168 (76)	169 (76)	170 (77)	172 (78)	168 (76)	168 (76)
Oil Consumption, lb.	3.75	4.23	1.05	2.52	3.88	6.97
Coolant Out Temp. °F (°C)	179 (82)	179 (82)	180 (82)	180 (82)	180 (82)	179 (82)
Fuel Rate, lbs/hr	3.80	3.80	3.79	3.80	3.81	3.81
Load, lb-ft	26.8	27.5	26.9	24.8	28.9	26.1

engine do not provide a basis for recommending changes in the limits for the maximum 90 percent and end point distillation temperatures in Federal Specification VV-F-800D.

C. Accelerated Stability

VV-F-800D diesel fuels are required to meet the accelerated stability limit of 1.5 mg/100 mL maximum total insolubles. It is presumed that fuels failing this requirement

may cause injector fouling to occur in engines operating on the nonspecification fuel for an undetermined time period. A procedure being developed at Belvoir Fuels and Lubricants Research Facility (BFLRF) at Southwest Research Institute (SwRI) for evaluating injector nozzle fouling tendencies of fuels was utilized to evaluate a series of fuels with accelerated stability values both within and above the specification limits.(14) The Injector Fouling Bench Test (IFBT) employed in this program was described in Appendix B of the report "Thermal Oxidative Stability of Diesel Fuels," Interim Report BFLRF No. 205 (15), and is Appendix C of this report.

The IFBT was conducted with two injector systems: the Detroit Diesel and the Bosch APE 113 injectors. For each injector system, the procedure requires 22 gallons of fuel heated to 78°C and injected through the heated nozzle so that the fuel spray temperature is about 288°C. Each test is run 8 hours per day for five days for a total of 40 hours. The procedure is described in more detail in Appendix C. Six fuels have been evaluated in this program, and their properties are shown in TABLE 12. The fuels include a reference DF-2, a commercial diesel fuel, a MIL-F-46162B referee grade fuel with no stabilizer additive, a MIL-F-46162B referee grade fuel with the stabilizer additive, an experimental referee grade Type II fuel, and a naval distillate fuel. Both the MIL-F-46162B referee fuels were prepared from the same base fuel.

The results of seven tests are shown in TABLE 13 for Detroit Diesel injector and in TABLE 14 for the Bosch system. The first test conducted in both systems was with Cat 1H2/1G2 as the test fuel. The test in the Detroit Diesel system was not completed because the temperature of the nozzle tip heating block was excessively high at the beginning. Some wires in the apparatus were damaged and had to be replaced. The pintle eventually stuck, and the test was stopped. The Bosch system was operational during the first test, but the fuel supply was exhausted at 39.5 hours.

The last three items in TABLES 13 and 14 - Airflow, Pintle Demerits, and Tube Deposit Ratings - are approaches to measuring the deposits or effect of deposits formed on the injector pintles while flowing the hot test fuel through the injection system for 40 hours. Airflow is measured through the clean injectors before the test and after 40 hours of test. Any loss in airflow represents the restriction in the injector caused by deposits formed on the pintle and orifice surfaces. Pintle demerits represent a visual rating of the deposits on the pintle surfaces based on a CRC scale. Tube deposit ratings are

TABLE 12. Fuel Properties

Properties	ASTM Test Method	AL-14823-F Cat 1H2/1G2	AL-14941-F Lo S Diesel	AL-14940-F MIL-F-46162B With No Stabilizer	AL-14948-F MIL-F-46162B With MIL-S-53021 Stabilizer	AL-14751-F Type II Ref. Gr.	AL-13279-F MIL-F-16884H NDF
Gravity, °API,	D 1298	34.5	33.7	31.6	31.2	24.8	35.2
Density at 15°C,	D 1298	0.8520	0.8526	0.8671	0.8692	0.9048	0.8484
Distillation, °C	D 86						
IBP		210	177	172	173	196	192
10% recovered		240	223	207	204	231	222
50% recovered		272	291	271	276	314	262
90% recovered		324	332	337	339	385	322
End point		350	373	367	371	>404	348
% residue		1.5	1.0	1.5	1.0	ND*	1.5
Flash point, °C		88	74	67	62	83	77
Cloud point, °C		-9	-2	-16	-18	-19	-11
Pour point, °C		-13	-3	-23	-23	-25	-30
K. Vis. at 40°C, cSt	D 445	3.11	3.31	2.86	2.94	7.0	2.75
Cetane number	D 613	50.5	50.5	48.0	43.3	40.2	50.5
Cetane index	D 976	47.7	49.5	42.6	43.1	39.3	46.6
Sulfur, wt%	D 2622	0.42	0.12	1.02	1.05	0.92	0.20
Total Acid No., mg KOH/g	D 664	0.02	0.04	0.01	0.03	ND	0.09
Cu corrosion, 3 hr at 99°C	D 130	1A	1A	1A	1A	1A	1A
Ash, wt%	D 482	<0.01	<0.001	0.001	<0.001	<0.01	0
Carbon residue on 10% bottoms, wt%	D 524	0.01	0.13	0.17	0.13	0.15	0.16
Carbon, wt%	D 3178	86.35	86.66	85.89	86.28	ND	86.12
Hydrogen, wt%	D 3178	12.95	12.69	12.31	12.31	ND	12.89
Net heat of combustion,	D 240						
MJ/kg		42.586	42.327	42.033	42.124	ND	42.68
Btu/lb		18,309	18,200	18,071	18,110	ND	18,349
Existent gum, mg/100 mL	D 381	10.1	7.1	24.2	7.5	326	29.5
Accelerated stability, mg/100 mL	D 2274	3.97	0.17	0.23	1.74	0.56	3.24
Particulates, mg/L	D 2276	2.5	0.8	1.8	5.3	6.5	103
Appearance	D 4176	C and B	C w/s tr sed	Cloudy	C and B	ND tr sed	ND

* ND = Not determined.

another means of evaluating the pintle deposits using two different procedures: a visual rating scale and a light reflectance measuring device. These rating techniques were adapted from procedures used for rating JFTOT tubes in ASTM D 3241. Another technique also used to evaluate the extent of deposits formed on the pintle surfaces was the Deposit Measuring Device developed at BFLRF. This technique measures the dielectric strength of the deposits. The dielectric rating can then be converted to deposit thickness. Measurements are made at numerous points all along the surface of the pintle.

TABLE 13. Detroit Diesel IFBT Operating Conditions and Test Results

Test No. Code No.		Test 1D AL-14823-F	Test 2D AL-14823-F	Test 3D AL-14941-F	Test 4D AL-14940-F	Test 5D AL-14948-F	Test 7D AL-14751-F	Test 10D AL-13279-F
Fuel	Goal	Cat 1H2/1G2	Cat 1H2/1G2	Low S Diesel	MIL-F-46162B With No Stabilizer	MIL-F-46162B With MIL-S-53021 Stabilizer	Type II Referee Grade	MIL-F-16884H NDF
Test hours	40	37*	40	40	40	40	40	40
Speed rpm	1000	1000	1000	1000	1000	1000	1000	1000
Fuel flow, gal/h	0.5	-	-	-	-	-	-	-
Fuel reservoir temp, °C, avg	-	79	79	78	78	77	78	78
Spray temp, °C, avg	288	280	263	261	260	261	260	260
Nozzle tip heating block temp, °C, avg	-	307	303	308	321	320	315	314
Injection pressure, psi before/after	-	142/0	139/143	138/132	144/142	137/136	135/133	142/138
Leak down, (dP: 15 sec minimum) before/after	-	30/stuck	29/26	26/23	38/32	52/28	48/55	51/46
Fuel flow, mL/1000 strokes before/after	-	89/8	97/95	96/96	96/93	94/94	93/94	94/92
Airflow gauge before/after	-	6/stuck	5.0/5.1	6.5/5.0	5.2/3.8	5.0/4.7	4.5/4.45	2.8/2.85
Percent loss			(2)**	24	27	6	1.1	(1.8)
Pintle demerits								
Nonrubbing	-	8.85	6.75	7.25	8.75	6.40	2.80	6.70
Rubbing	-	6.60	5.15	5.20	6.40	6.15	5.25	6.55
Tip	-	5.66	5.50	5.75	4.20	5.80	5.20	6.35
Tube deposit rating (TDR)***								
Spun/station		43/31	46/31	37/27	43/26	39/47	25/30	38/47
Visual rating		4	4.5	4.5	4.5	4	4	4

* During the first two hours of this test, the nozzle tip heating block temperature was well above 600°F, which may have distorted the pintle.
** Number in ( ) represent a gain in airflow.
*** Highest TDR measured on pintle. See Appendix C.

TABLE 14. CLR-D Bosch APE 113 IFBT Operating Conditions and Test Results

Test No. Code No.		Test 1B AL-14823-F	Test 2B AL-14823-F	Test 3B AL-14941-F	Test 4B AL-14940-F	Test 5B AL-14948-F	Test 7B AL-14751-F	Test 10B AL-13279-B
Fuel	Goal	Cat 1H2/1G2	Cat 1. 2/1G2	Low S Diesel	MIL-F-46162B With No Stabilizer	MIL-F-46162B With MIL-S-53021 Stabilizer	Type II Referee Grade	MIL-F-16884H NDF
Test hours	40	39.5	40	40	40	40	40	40
Speed rpm	1000	1000	1000	1000	1000	1000	1000	1000
Fuel flow, gal/h	0.5	-	-	-	-	-	-	-
Fuel reservoir temp, °C, avg	-	78	78	78	78	77	77	77
Spray temp, °C, avg	288	261	261	261	260	261	261	260
Nozzle body heating block temp, °C, avg	154	153	155	154	154	159	159	150
Nozzle tip heating block temp, °C, avg	404	311	316	306	295	295	297	283
Injection pressure, psi before/after	-	2500/2400	2500/2375	2500/2500	2500/2440	2500/2500	2500/2450	2500/2450
Spray pattern before/after	-	VG*/G**	VG/VG	VG/VG	VG/VG	VG/VG	VG/VG	G/VG
Airflow, cu. ft./min at 100% lift before/after	-	0.090/0.086	0.085/0.087	0.121/0.093	0.903/0.076	0.085/0.078	0.082/0.076	0.0815/0.08
Percent loss	-	4.4	(2.4)***	23	18.9	8.2	7.2	0
Pintle demerits								
Nonrubbing	-	4.60	5.85	3.20	4.75	4.85	2.20	2.70
Rubbing	-	2.75	3.35	3.25	6.45	5.30	0	1.05
Tip	-	5.55	5.25	7.25	7.60	7.60	5.05	6.90
Tube deposit rating (TD%R)****								
Spun/station	-	34/72	26/70	20/72	31/42	33/48	9/47	23/69
Visual rating	-	4+	3.5	3.5	4.5	4.5	2	2.5

* VG - Very good.
** G - Good.
*** Number in ( ) represents gain in airflow.
****Highest TDR measured on pintle. See Appendix C.

Graphical representation of the data from these tests are shown in Figs. 14 through 21. Figs. 14 and 15 depict in bar charts the demerit ratings for the pintles from the Detroit Diesel and the Bosch systems, respectively, for each fuel. It is obvious that these ratings do not correlate with the accelerated stability values of the fuels. Figs. 16 and 17 are plots of percent airflow loss versus accelerated stability in the Detroit Diesel and Bosch systems. The unexpected trend observed in these plots is that the airflow loss is lower with the fuels having higher accelerated stability values. Figs. 18 and 19 show the TDR spun ratings plotted against accelerated stability ratings for the Detroit Diesel and Bosch systems, respectively. No correlation between TDR spun ratings and accelerated stability values is apparent. The last set of plots, Figs. 20 and 21, show the dielectric strength of the deposits formed by each fuel versus the accelerated stability values. As indicated earlier, the dielectric strength was measured at numerous points along the surface of the pintles. The values used in these plots were the highest measured values for each test fuel. Again there is no apparent correlation between the DMD measurements and accelerated stability values.

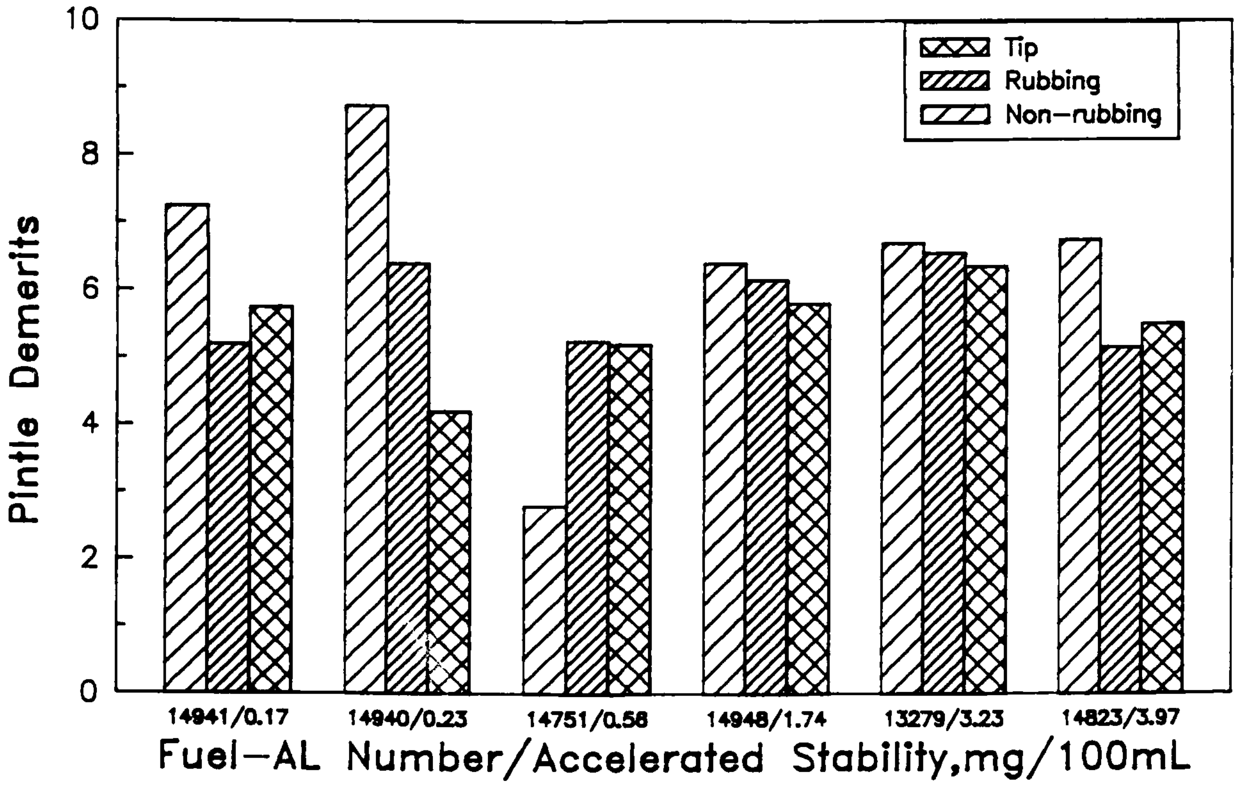

Figure 14. Pintle demerits for Detroit Diesel IFBT

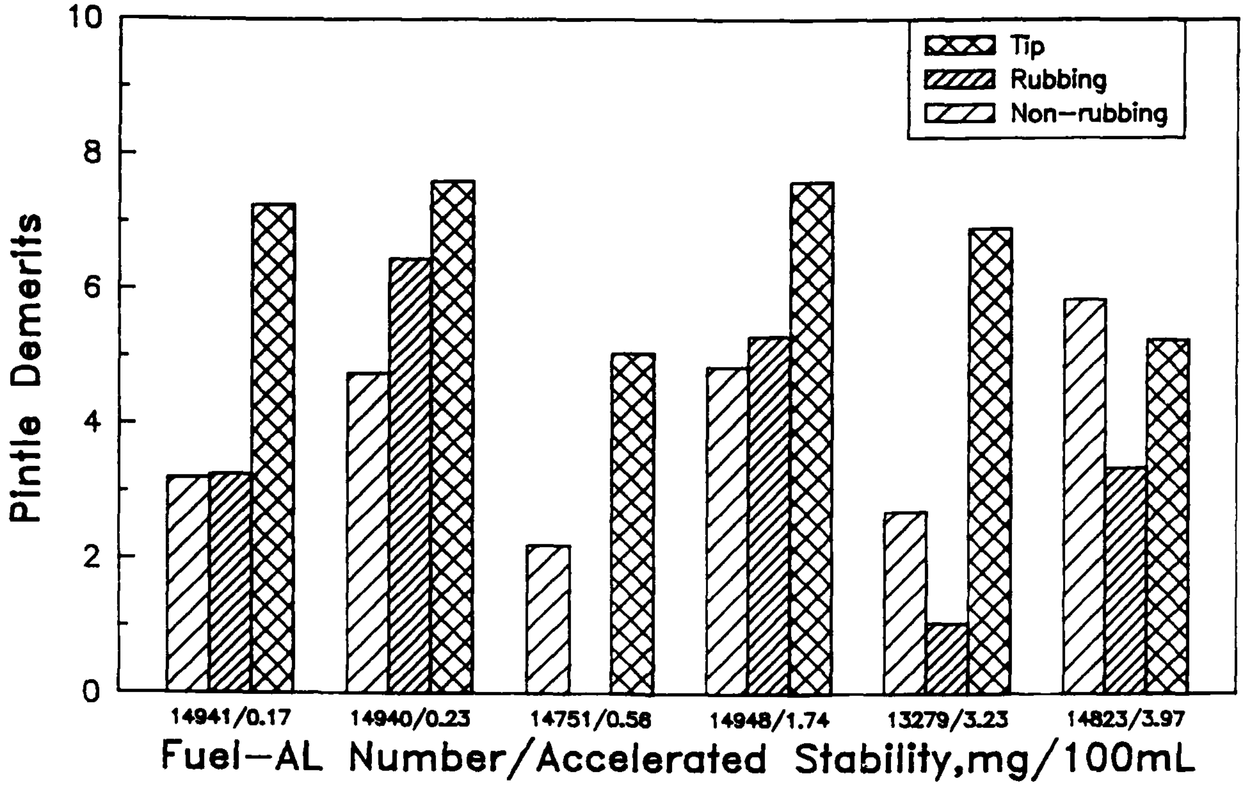

Figure 15. Pintle demerits for Bosch APE 113 IFBT

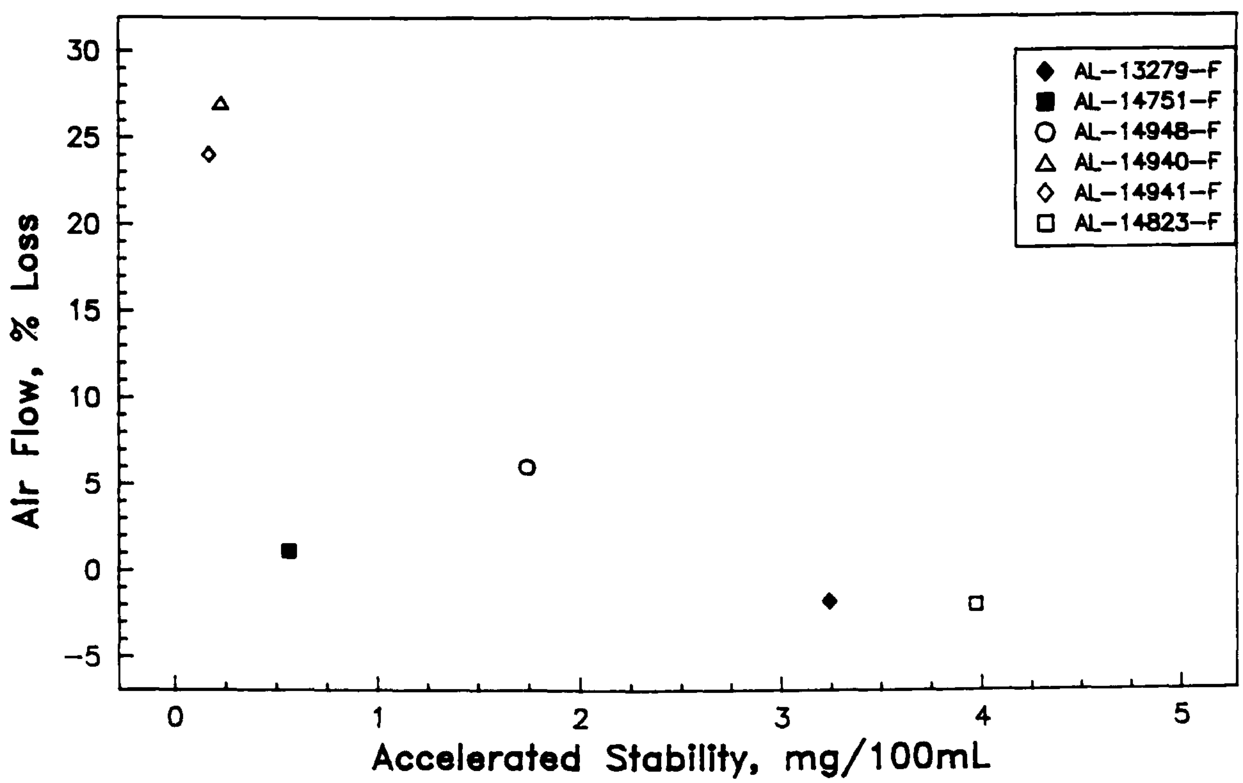

Figure 16. Airflow for Detroit Diesel IFBT

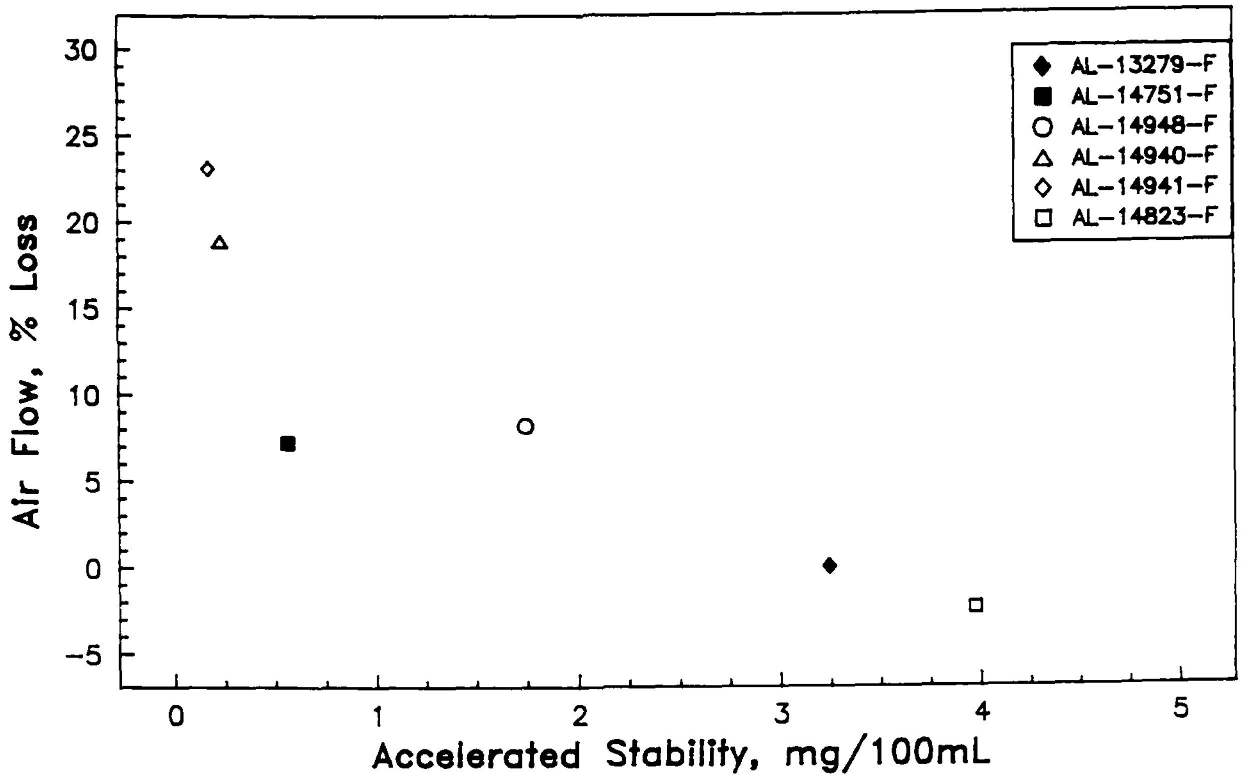

Figure 17. Airflow for Bosch APE 113 IFBT

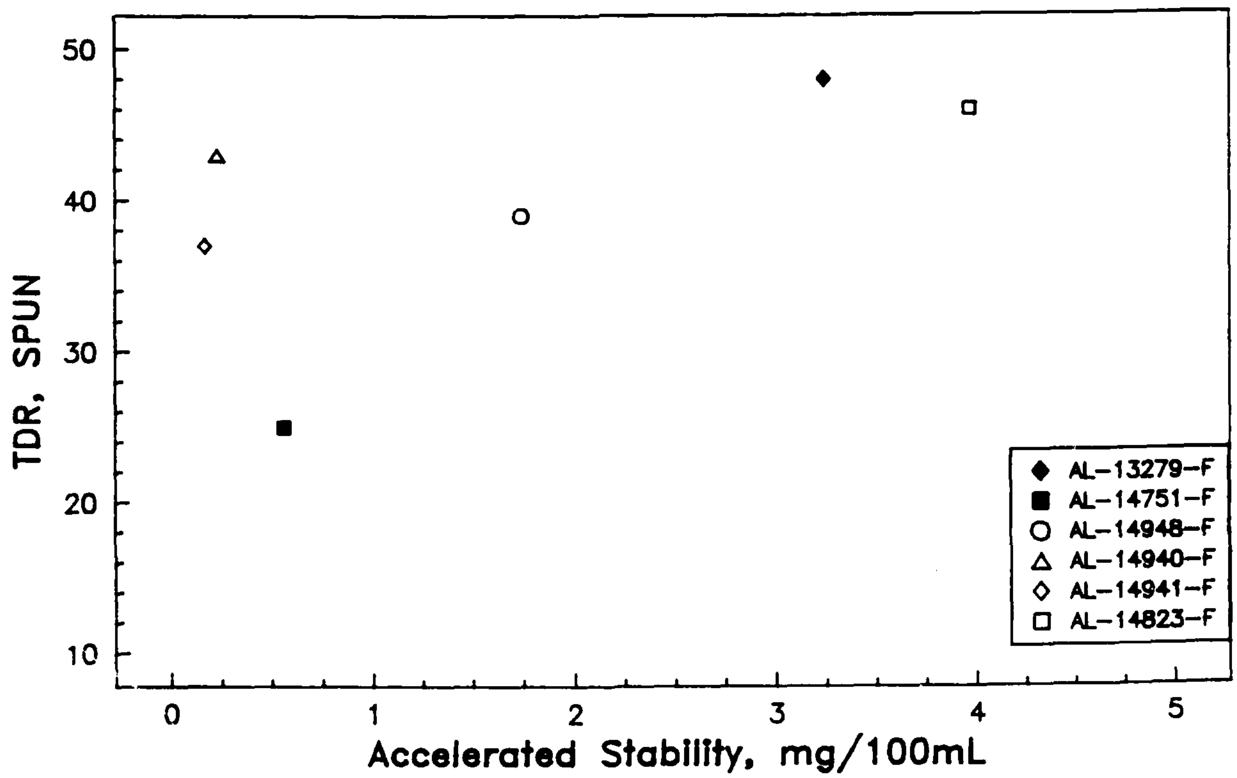

Figure 18. TDR for Detroit Diesel IFBT

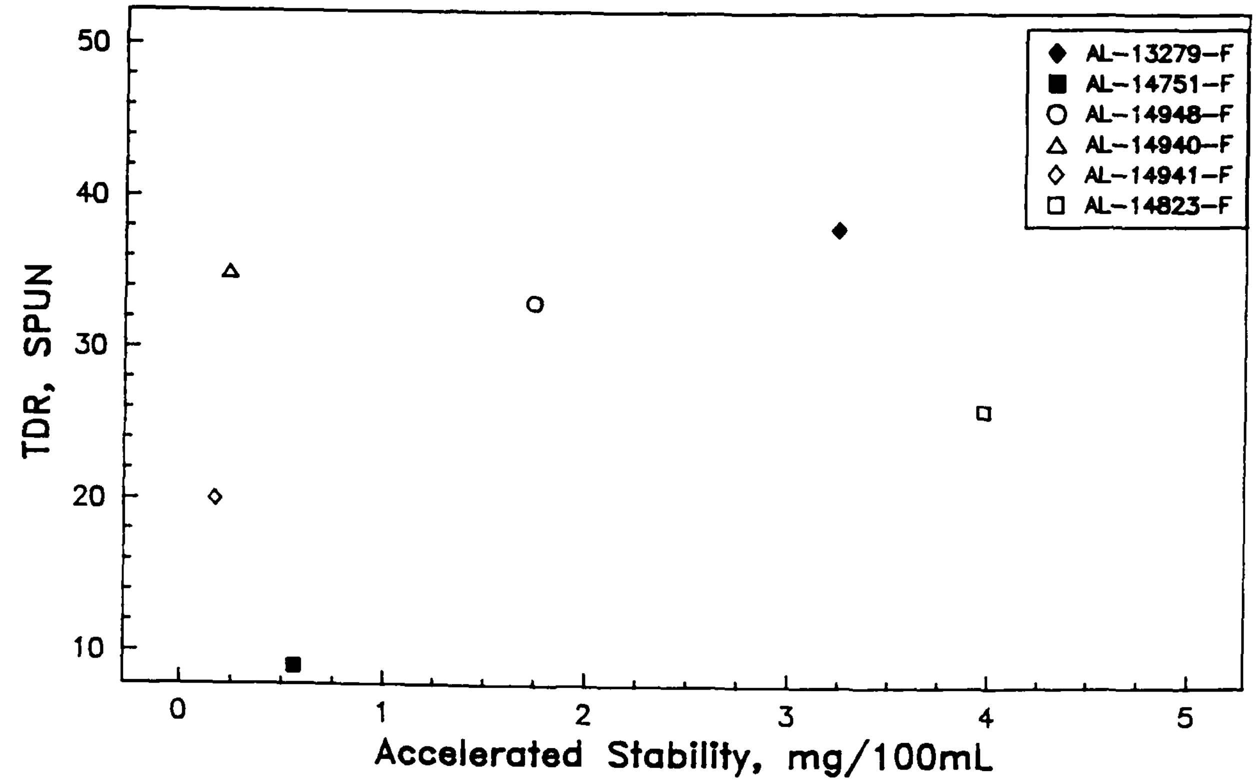

Figure 19. TDR for Bosch APE 113 IFBT

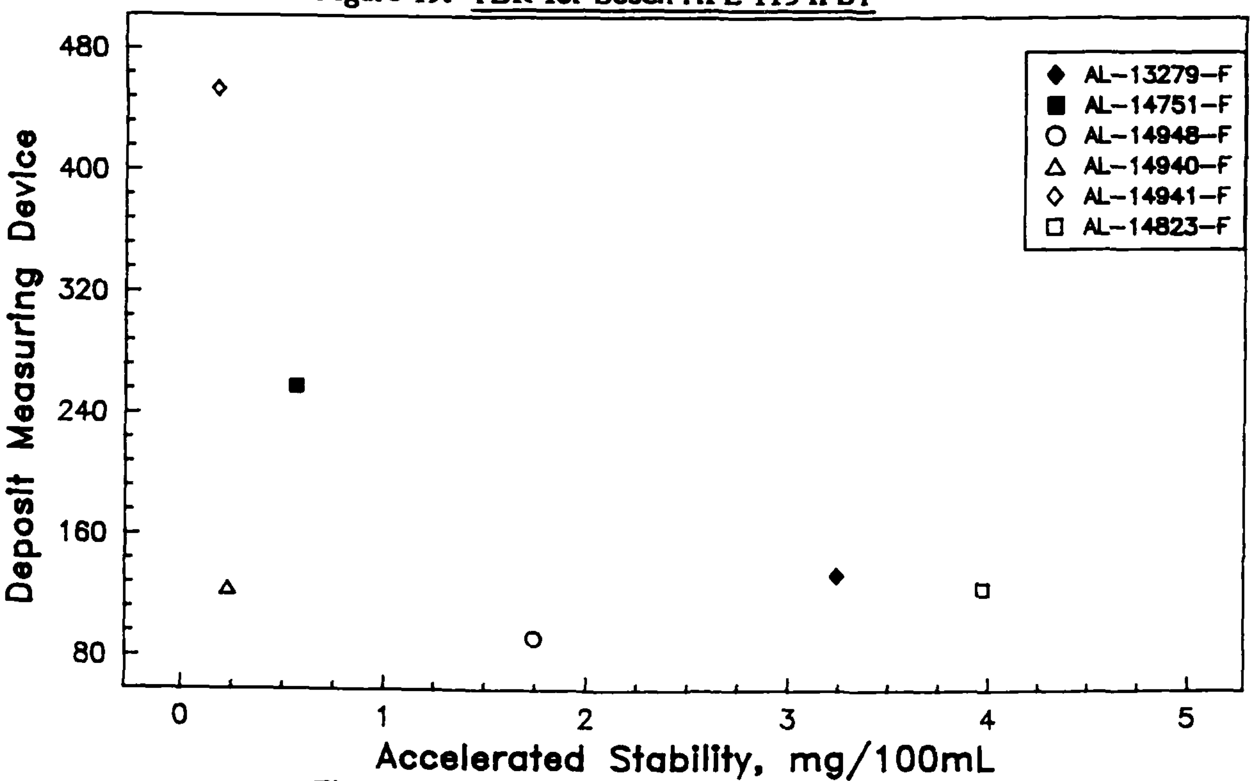

Figure 20. DMD for Detroit Diesel IFBT

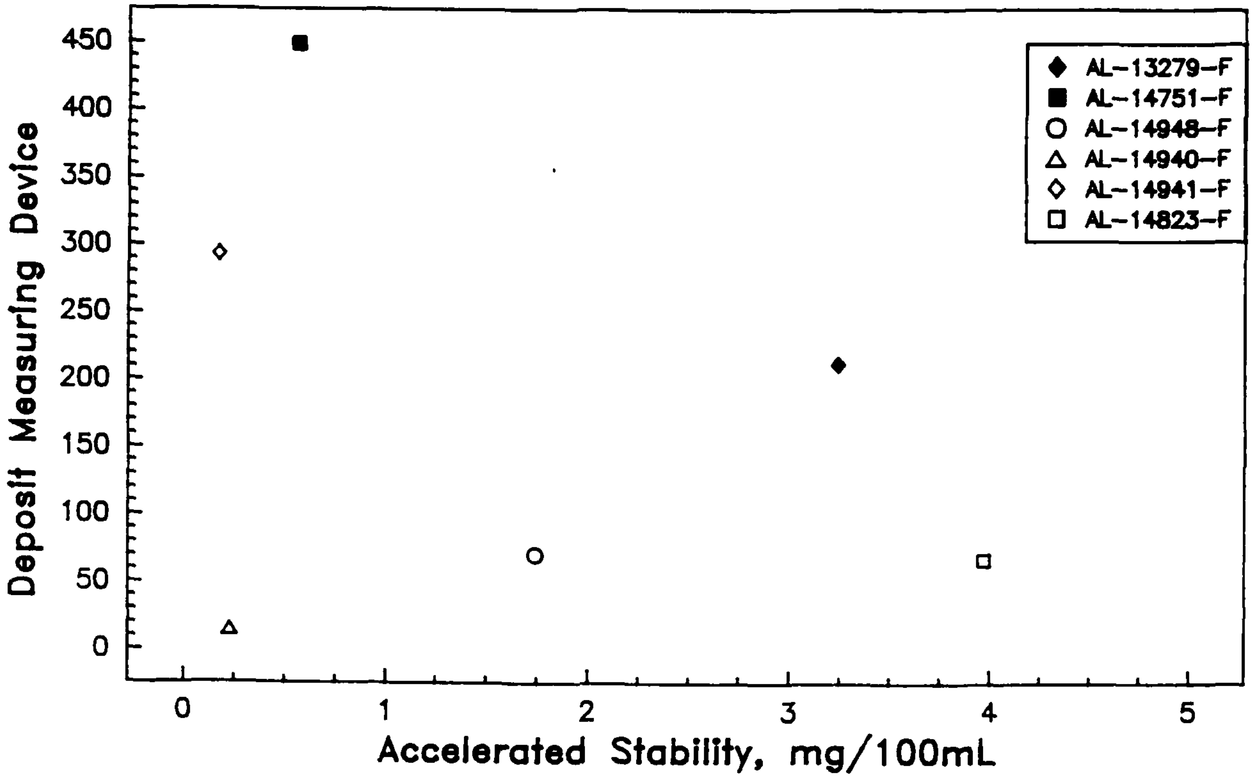

Figure 21. DMD for Bosch APE 113 IFBT

No correlation between D 2274 stability, D 3241 (thermal stability) breakpoint temperature of tube deposit, and IFBT pintle deposits (based on average deposit breakdown voltage by DMD) was apparent for the data summarized in TABLE 15. Based on these data, it appears that the level of accelerated stability is not the only fuel property that affects deposit formation on the pintles of the Detroit Diesel and the Bosch injector systems used in the Injector Fouling Bench Test procedure. The data do not provide a basis for recommending a variation in the level of accelerated stability limit as stated in VV-F-800D.

D. Carbon Residue

The carbon residue test is a measure of the carbonaceous material left in a fuel after all the volatile components are vaporized in the absence of air under prescribed test conditions. It is thought to give an approximation of the carbon-depositing tendencies of a fuel. Federal Specification VV-F-800D for diesel fuel, Grade DF-2, has a requirement

TABLE 15. Results of Stability Tests Compared to IFBT Pintle Deposits
(December 1986)

AL-Code Number	Fuel Description	Accelerated Stability, D 2274 Total Insolubles, mg/100 mL	Thermal Oxidation Stability Test, D 3241 Test No.	Temperature, °C (°F)	Breakpoint Temperature*, °C	Change in Pressure, mm of Hg	Preheater Deposit Code	TDR Spun Deposit Rating	Volume of Deposit by DMD, $cm^3 \times 10^{-7}$
14823-F	Cat 1H2/1G2 Diesel	4.0	1163-J	232 (450)	260	0	0	0	25
			1165-J	238 (460)		0	<2	8 at 51	43
			1168-J	243 (470)		0	<3 (Blue)	5 at 51	31
			1161-J	246 (475)		0	<3 (Blue)	4 at 48	32
			1176-J	260 (500)		0	<3 (Blue)	5 at 51	39 (80)+
14941-F	Low Sulfur Diesel	0.2	1178-J	232 (450)	240	0	2 (Blue)	4 at 51	36
			1170-J	246 (475)		0	3	10 at 51	55
			1174-J	260 (500)		0	>4P	14 at 51	112 (100)+
14940-F	MIL-F-46162B With No Stabilizer	0.2	1169-T	191 (375)	191	0	4P	37 at 48	29
			1166-T	218 (425)		0	>4P	32 at 40	45
			1164-T	232 (450)		3 at 150 min	>4P	35 at 32	38
			1162-T	246 (475)		125 at 92 min	>4P	30 at 26	40
			1177-T	260 (500)		125 at 41 min	>4P	27 at 22	48 (93)+
14948-F	MIL-F-46162B With MIL-S-53021 Stabilizer	1.7	1173-T	232 (450)	254	0	2	8 at 51	61
			1171-T	246 (475)		0	<3	10 at 51	43
			1204-G	252 (485)		0	<3	9 at 44	30
			1175-T	260 (500)		0	>4	16 at 51	69 (55)+
13279-F	MIL-F-16884-H NDF	3.2	1408-J	232 (450)	241	1 at 150 min	<2	12 at 54	54
			1411-J	288 (460)		0	<2	15 at 54	70
			1414-J	240 (464)		0	2	14 at 54	51
			1412-G	242 (468)		36 at 150 min	3	27 at 54	79
			1410-G	246 (475)		125 at 89 min	>4	25 at 54	72
			1413-G	260 (500)		125 at 37 min	>4	31 at 53	676 (404)+
14751-F	Type II Referee Grade	0.6	1370-J	204 (400)	206	0	1	6 at 51	37
			1372-J	208 (406)		0	<4	11 at 51	65
			1371-J	210 (410)		0	4	12 at 51	31
			1369-J	213 (415)		0	>4	12 at 44	47
			1368-J	218 (425)		0	>4	12 at 43	51
			1373-J	260 (500)		0	>4P	35 at 38	235 (75)+

* Breakpoint temperature, Code 3 inception temperature approximation.
** Simple addition of voltage reading along length of pintle divided by number of stations (31 for the Bosch and 24 for the Detroit).
+ Values determined in early 1988.

of 0.35 wt% maximum, carbon residue on 10-percent bottoms, measured by the Ramsbottom carbon residue procedure, ASTM D 524.

To attempt to determine the effect of a fuel with over-specification-limit carbon residue value, 99.65 vol% of a reference fuel (Cat 1H2/1G2) with a carbon residue on 10-percent bottoms value of 0.01 wt%, was blended with 0.35 vol% of marine fuel oil that had a carbon residue of 13.5 wt%. The resulting blend had a carbon residue on 10-percent bottoms value of 0.54 wt%. The properties of the Cat 1H2/1G2 fuel are given in TABLE 10, those of the marine fuel oil are shown in TABLE 16, and those for the blend are given in TABLE 17. As can be observed, the addition of the small amount of marine fuel oil to the reference fuel had a great effect on the accelerated stability, particulate contaminant, and existent gum values, which was not altogether anticipated.

TABLE 16. Properties of Marine Fuel Oil Sample

Fuel Sample No.	Test Method	Marine F.O. FL-0348-F
Gravity, °API	D 287	12.0
Specific Gravity, 60°F		0.9861
Density, lb/gallon		8.212
Viscosity at 104°F (40°C), cSt	D 445	710.71
at 122°F (50°C), cSt	D 445	328.88
Flash Point, °F	D 93	199
Carbon Residue, wt%	D 524	13.5
Sulfur, wt%	XRF	2.40
Corrosion, Cu. Strip, 50°C	D 130	1B
Pentane Insolubles, wt%	D 893	10.10
Toluene Insolubles, wt%	D 893	1.69
Carbon, wt%	--	86.52
Hydrogen, wt%	--	10.40
Heat of Combustion	D 240	
Gross, Btu/lb		17,966
Net, Btu/lb		17,016
Net, Btu/gallon		139,735

TABLE 17. Test Fuel Blend

Composition	AL-16238-F
Cat 1H2/1G2, vol% (AL-15706-F)	96.65
Marine Fuel Oil, vol% (FL-0348F)	0.35
Properties	
Gravity, °API	34.1
Density at 15°C	0.8540
Visual Appearance	Dark
Color, D 1500	>8
Flash Point, °C	84
Pour Point, °C	-21
Distillation, °C	
IBP	209
10% recovered	241
50% recovered	273
90% recovered	323
End Point	348
% Residue	1
% Recovered	99
Kinematic Viscosity at 40°C	3.17
Accelerated Stability, mg/100 mL	10.2
Particulate Contaminants, mg/L	27.3 mg/100 mL
Existent Gum, Steam Jet, mg/100 mL	201
Sulfur, wt%	0.42
Cu Corrosion, 3 hr at 50°C	1A
Ash, wt%	<0.01
Total Acid Number, mg HOH/100 g	0.03
Cetane Number	48
Cetane Index	47
Carbon Residue on 10% Bottoms	0.54
Water, Karl Fischer Method, ppm	192
JFTOT at 260°C	
ΔP	0*
Visual Rating	>4 (P)
DMD Maximum Thickness, cm x 10^{-7}	285 at 32
Deposit Volume, cm^3 x 10^{-7}	637

* Filter plugged at 100 minutes and was removed to complete test.

The blend, identified as AL-16238-F, was used in an injector fouling bench test, employing the Detroit Diesel and the Bosch APE 113 injector systems. The results of the 40-hour test are given in TABLE 18 for the Detroit Diesel and TABLE 19 for the Bosch. Tests of the airflow through the injector nozzles for both systems, before and

TABLE 18. Detroit Diesel IFBT Operating Conditions and Test Results

Test No. Code No. Fuel	Goal	Test 11D AL-16238-F High Carbon Residue Fuel
Test Hours	40	40
Speed rpm	1000	1000
Fuel Flow, gal/h	0.5	--
Fuel Reservoir Temp., °C, Avg.	--	80
Spray Temp., °C, Avg.	288	260
Nozzle Tip Heating Block Temp., °C, Avg.	--	303
Injection Pressure, psi		
Before/After	--	152/140
Leak Down, (dP: 15 sec Minimum)		
Before/After	--	58.9/53.6
Fuel Flow, mL/1000		
Strokes Before/After	--	98/90
Airflow Gauge		
Before/After	--	2.88/1.95 (Pintle Stuck)
Percent Loss	--	32
Pintle Demerits		
Nonrubbing	--	8.60
Rubbing	--	6.50
Tip	--	7.55
Tube Deposit Rating (TDR)		
Spun/Station	--	44/30
Visual Rating	--	4
DMD, average voltage	--	40

TABLE 19. CLR-D Bosch APE 113 IFBT Operating Conditions and Test Results

Test No. Code No. Fuel	Goal	Test 11B AL-16238-F High Carbon Residue Fuel
Test Hours	40	40
Speed rpm	1000	1000
Fuel Flow, gal/h	0.5	--
Fuel Reservoir Temp., °C, Avg.	--	79
Spray Temp., °C, Avg.	288	257
Nozzle Body Heating Block Temp., °C, Avg.	154	155
Nozzle Tip Heating Block Temp., °C, Avg.	404	293
Injection Pressure, psi Before/After	--	2500/2500
Spray Pattern Before/After	--	VG*/VG
Airflow, cu. ft/min at 100% Lift Before/After	--	0.0816/0.0535
Percent Loss	--	34
Pintle Demerits		
Nonrubbing	--	4.90
Rubbing	--	3.25
Tip	--	6.65
Tube Deposit Rating (TDR)		
Spun/Station	--	29/73
Visual Rating	--	4
DMD, average voltage	--	29

* VG = Very Good.

after the 40-hour runs, gave a 32-percent reduction for the Detroit Diesel (which also had a stuck pintle) and 34-percent reduction for the Bosch system. The reduction in airflow apparently was caused by deposits formed in the injectors; however, these deposits cannot be attributed solely to the high carbon residue value for this fuel since existent gum, accelerated stability, and particulate content were also high.

V. SUMMARY OF RESULTS

The overall conclusion from this work is that the fuel properties investigated cannot be relaxed to any significant extent and still permit optimum performance in **all** the engines and components currently in the Army system, under all climatic conditions.

Based on the cold-starting work reported here, the cetane number limit cannot be lowered below the current 40 minimum because the DD 6V-53T engine does not start readily in cold temperatures on low cetane number fuel. There may be other engines in the system that have low tolerance for low cetane number fuels. In contrast, the LDT-465-1C, the NHC-250, and 6.2L engines started at much lower temperatures on lower cetane number fuel. The data in this work tend to indicate that the NHC-250 is the most tolerant toward cetane number of the engines tested in this program.

The evaluation of viscosity effects show that the injection systems are critically affected by the viscosity of the fuel. For the LTD-465 and the 6V-53T systems, fuels with low viscosities tended to leak past the barrel and plunger assemblies, resulting in a decreased flow rate. The fuels with higher viscosities tended not to fill the pump in the time available, also resulting in decreased fuel flow. The DD 6V-53T engine appeared to start more readily on higher viscosity fuels of equivalent cetane number. The LDT-465-1C and the NHC-250 engines started more readily on the lower viscosity fuels. Personnel at Detroit Diesel Allison have stated that the injection pump used in the 6.2L engine is limited to handling fuel with a maximum kinematic viscosity of 20 cSt; therefore, when higher viscosity fuels are chilled, they cannot be injected into the combustion chamber. Due to the characteristics of different engines and injection systems, it is concluded that current viscosity limits in VV-F-800D cannot be varied significantly.

Under certain specific conditions, fuels with cetane numbers lower than 40, perhaps as low as 35, could be used. These conditions are: 1) in cold climates if no sensitive engines such as the 6V-53T are in the fleet and 2) in warm climates where the ambient temperature will not go below 7°C (45°F).

The evaluation of fuels with high 90-percent and end-point distillation did not provide conclusive data for recommending variations to distillation limits found in Federal Specification VV-F-800D.

The data developed with seven different fuels having a range of accelerated stability values evaluated in the Injector Fouling Bench Test with the Detroit Diesel and Bosch injector systems showed little, if any, correlation between the level of accelerated stability values and injector plugging. Apparently other fuel properties also affect the level of deposit formation in the injectors of these systems.

The fuel with high carbon residue value evaluated on the Injector Fouling Bench Test resulted in significant deposit formation in both the Detroit Diesel and Bosch injection systems; however, these deposits cannot be attributed solely to the carbon residue value, since other properties of this fuel were excessively over limits.

VI. CONCLUSIONS

Variations in the limits of the properties investigated cannot be recommended for Federal Specification VV-F-800D; however, an example of a variable quality diesel fuel specification is shown in Appendix D.

Opportunities exist for relaxing some of the VV-F-800 specification requirements without impacting vehicle operations. An obvious area is relaxing the cetane and upper viscosity limits in regions where the ambient temperature remains above 7°C Relaxed fuel properties can improve fuel availability (cost and quality related) to commanders for local procurements over limited time periods for accomplishing high fuel quantity maneuvers. Increased maintenance (reduced oil change period and fuel filters, and premature maintenance for unstable fuels) may be experienced with prolonged use of relaxed specification fuels. Economic advantages of low-viscosity (low-density) fuels may be offset by higher fuel volume use to accomplish equivalent missions. High-energy content (high-density) fuels may lead to engine overfueling and increased visible signature (smoke). Minimum relaxed deviations from VV-F-800 specifications in the direction of fully relaxed values in the variable quality fuel specification could cause reduced engine power, performance, and endurance debits. Appendix D presents an

example of a variable quality fuel specification compared with the standard VV-F-800 and the emerging ASTM emergency fuel requirements.

Since fuel physical properties are all reflections of the fuel's underlying chemical structure, these physical properties are necessarily interrelated, as illustrated in Appendix E. Engine response to fuel physical and chemical properties is a complex function of all these properties, while the current specifications place limits on each individual property. The specifications thus may not adequately consider synergistic effects in fuel properties. This synergism can be seen in the impacts of both fuel viscosity and cetane number on startability in the Detroit Diesel 6V-53T engine (Fig. 1). Based on this figure, for example, the cetane requirement could be reduced as fuel viscosity increased.

There is potential for relaxing other specification requirements, but with some long-term disadvantages. These disadvantages could include increased routine maintenance, shortened engine life, or increased component replacement rates. Unfortunately, there is insufficient data to quantify these costs.

VII. RECOMMENDATIONS

The following actions for development of variable quality fuels specifications are recommended:

- Improve bench tests for correlation of properties with engine dynamometer tests and full-scale vehicle performance.
- Develop vehicle/equipment performance models for variable quality fuels.
- Conduct limited vehicle tests to validate practical limits of a variable quality fuel specification developed from performance model(s).
- Initiate development of specification handbook and expert system for proper implementation of locale-dependent variable quality fuel specification.

A de facto variable quality fuel specification currently exists in the Defense Fuel Supply Center (DFSC) specification waivers. Formalization of this system by allowing additional waiver opportunities may encourage fuel suppliers to further reduce the quality of fuels offered to the government without compensating reductions in cost. This

possibility could be investigated by determining if DFSC issuance of a waiver to a fuel supplier increases the likelihood of the supplier requesting other waivers.

Fuel properties affect the costs of operation of a vehicle, and a procurement specification is an attempt to control these costs to a minimum level consistent with obtaining adequate supplies of fuel. The current VV-F-800 specification is based on experience in balancing fuel costs, fuel availability, and vehicle operating costs. The cost impacts of variations in individual fuel properties needs to be studied so that informed decisions on either granting waivers (current system) or allowing regional adjustments in specification limits (variable quality) can be made. Such a cost study would be valuable even without a variable quality fuel specification, if properly applied. For example, one could visualize an expert system that would provide DFSC cost estimates of the increase in fleet operating costs, in cents per gallon, that would result from fuel specifications that depart from some optimal value. This estimate would be used in evaluating fuel bids in order to procure fuels that would minimize total fleet operating costs.

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APPENDIX A

Army Cold Startability Procedure

APPENDIX A

Army Cold Startability Procedure

8:00 AM

Check battery condition by measuring and recording hydrometer reading and temperature for each cell of the batteries.

Disconnect battery charger.

Record the before test information on the data form.

Reset the timer.

Turn on chart recorder.

Crank engine until it starts, according to procedure for each engine, for a maximum of 2 minutes (1.5 minutes for the GM 6.2L).

Record the after information on the data form.

Turn off chart recorder.

Connect battery charger.

3:00 PM

Repeat above procedure on same fuel.

Change fuel as indicated below after 2 valid runs on each fuel.

Turn off cooling.

Remove the suction line and return line from the fuel can. Place the suction line into the can containing approximately 1 gallon of the new fuel. Place the return line into the dump can.

Fire the engine, letting it run for 20 seconds before shutting down.

Change the secondary filter.

Fire the engine and run at least 1 gallon of the new fuel through the engine. The fuel should be emptied from the engine into the dump can. After 1 gallon has been run through, shut down the engine.

Place both fuel lines into the fuel can containing 1 gallon of new fuel. Fire the engine and burn approximately 0.25 gallons of fuel while the engine runs at 800 to 900 rpm. After 0.25 gallons has been burned, shut down the engine.

Refill the fuel can with the test fuel and turn on the cooling for the next day's testing.

APPENDIX B

Cold-Start Test Data

TABLE B-1. Cold-Start Tests With DD 6V-53T Engine

Fuel	AL No	Test No	Date	Time	Cranking Speed, rpm	Sec. to Start*	Fuel wt Before, kg	Fuel wt After, kg	Fuel Used, kg	Water In Before, °C	Water In After, °C	Oil Sump Before, °C	Oil Sump After, °C	Air Box Before, °C	Air Box After, °C	Exhaust Before, °C	Exhaust After, °C	Fuel Before, °C	Fuel After, °C	Kinematic Vis, cSt†	Starting Aids	Set Temp, °C
Reference	13990.	1.	4-24	800.	205.	3.8	3.31	3.26	.05	19.1	20.8	16.2	18.8	18.9	19.4	19.4	42.8	13.4	19.3	3.35	n	10.0
	13990.	2.	4-25	805.	200.	120.0	2.78	2.62	.16	2.2	3.2	1.2	2.0	2.1	2.1	1.6	6	1.6	1.6	5.2	n	1.7
	13990.	3.	5-6	1600.	224.	95.4	1.59	1.26	.33	3.8	9.0	2.9	12.0	3.6	6.0	3.1	56.1	3.2	3.6	4.9	n	1.7
	13990.	4.	5-7	800.	226.	94.0	1.29	.920	.37	3.8	13.8	2.6	19.9	3.5	1.6	3.2	60.6	3.3	3.4	4.9	n	1.7
	13990.	5.	5-7	1600.	225.	94.1	2.51	2.19	.32	3.6	10.1	2.7	10.7	3.6	6.3	-.3	55.6	-.1	-.4	5.6	n	1.7
	13990.	6.	5-8	800.	220.	92.2	2.20	1.78	.42	3.6	14.6	-.6	20.4	3.4	7.9	-.2	61.7	-.3	3.6	4.9	n	1.7
	13990.	7.	5-8	1500.	230.	80.3	1.83	1.47	.36	3.8	14.9	-.3	19.2	3.6	3.2	-.1	61.1	-.2	3.8	4.9	n	1.7
A40	14010.	8.	5-9	800.	232.	120.0	2.97	2.79	.18	3.8	5.4	-.4	5.1	3.6	3.8	-.2	4.5	-.2	3.4	2.16	n	4.4
	14010.	9.	5-9	1500.	230.	118.9	2.79	2.40	.39	4.0	19.7	-.3	21.7	3.7	8.9	-.1	63.0	-.1	5.8	2.16	n	4.4
	14010.	10.	5-10	800.	230.	120.0	2.35	2.15	.20	3.7	5.4	2.7	5.4	3.3	3.5	-.2	6.7	-.2	-.1	2.16	n	4.4
	14010.	11.	5-10	1500.	220.	60.0	2.19	1.88	.31	7.1	17.2	6.1	22.7	7.0	10.6	6.4	60.9	6.3	6.7	1.88	n	7.2
	14010.	12.	5-13	600.	230.	72.3	1.80	1.51	.29	7.0	17.7	6.0	23.7	6.8	10.9	6.2	60.4	6.3	6.8	1.88	n	7.2
	14010.	13.	5-13	1500.	226.	59.0	1.26	1.05	.21	6.9	15.3	6.0	23.7	6.8	10.1	6.3	56.9	6.4	7.0	1.88	n	7.2
	14010.	14.	5-14	800.	356.	53.5	1.87	1.62	.15	6.9	15.9	5.9	20.9	6.8	10.4	6.4	60.4	6.9	6.7	1.86	n	7.2
	14010.	15.	5-14	1500.	208.	39.1	1.66	.000	.00	10.8	15.2	9.8	18.3	10.7	12.4	10.1	57.6	10.3	10.2	1.75	n	10.0
	14010.	16.	5-15	800.	286.	31.4	2.61	2.47	.14	10.6	11.0	9.7	15.7	10.5	12.6	9.6	57.4	10.0	10.6	1.76	n	10.0
	14010.	17.	5-15	1500.	280.	50.5	2.46	2.29	.27	10.8	16.6	9.7	17.6	10.6	12.4	10.0	59.7	10.1	10.2	1.75	n	10.0
	14010.	18.	5-16	800.	310.	31.3	2.29	2.13	.16	10.4	15.0	9.4	18.4	10.2	12.6	9.7	57.9	9.6	10.4	1.77	n	10.0
	14010.	77.	6-28	1500.	246.	40.0	2.52	2.24	.28	1.9	9.7	0.0	12.9	1.1	4.2	.8	56.3	-.7	1.3	2.15	v	-1.1
	14010.	78.	7-1	800.	281.	34.5	2.21	1.97	.24	-1.1	5.1	-2.3	8.4	-1.6	2.6	-2.2	63.6	-1.5	-.8	2.18	v	-1.1
	14010.	79.	7-1	1500.	256.	44.2	1.96	1.77	.19	-.4	3.3	-1.4	4.4	-.3	2.9	-1.3	58.1	-1.7	-.4	2.17	v	-1.1
B40	14013.	19.	5-16	1500.	290.	5.4	2.98	2.83	.15	10.7	16.8	9.6	18.2	10.3	13.7	9.3	63.6	9.8	10.6	15.5	n	10.0
	14013.	20.	5-17	800.	280.	6.0	2.82	2.71	.11	10.6	14.5	9.6	15.7	10.4	13.1	9.8	61.9	10.0	10.3	15.5	n	10.0
	14013.	21.	5-17	1500.	280.	4.9	2.70	2.57	.13	10.8	15.9	9.7	18.1	10.5	13.7	9.9	65.4	10.1	10.6	15.5	n	10.0
	14013.	22.	5-21	800.	306.	8.0	2.56	2.40	.16	10.7	18.1	9.3	16.6	10.5	13.2	9.9	56.5	10.1	10.8	15.5	n	10.0
	14013.	25.	5-22	1500.	290.	11.2	2.16	1.98	.18	7.8	14.8	6.6	17.6	7.4	11.9	6.7	68.2	7.0	7.9	17.5	n	7.2
	14013.	26.	5-23	800.	230.	3.8	2.01	1.84	.17	12.9	19.3	9.7	21.8	12.9	16.6	13.0	66.4	12.3	13.7	14.0	n	10.0
	14013.	27.	5-23	1500.	220.	15.9	1.83	1.66	.17	7.0	13.3	6.1	15.7	6.8	10.7	6.1	66.8	6.2	7.0	18.0	n	7.2
	14013.	28.	5-24	800.	230.	14.7	1.66	1.44	.22	6.1	14.7	5.1	18.2	6.0	10.9	5.4	69.0	5.6	6.6	18.0	n	4.4
	14013.	29.	5-24	1500.	246.	38.4	1.44	1.26	.18	4.7	8.8	3.6	10.7	4.1	8.1	3.6	65.7	3.8	4.1	20.2	n	4.4
	14013.	30.	5-27	800.	213.	20.0	1.27	1.04	.23	4.1	11.9	3.2	15.7	3.9	8.6	3.4	66.8	3.6	4.2	20.3	n	4.4
	14013.	31.	5-27	1500.	250.	25.7	1.05	.860	.19	4.3	11.8	3.3	15.7	4.2	8.8	3.8	68.9	4.2	4.3	20.0	n	4.4
	14013.	80.	7-2	800.	240.	18.0	2.74	2.61	.13	-.6	6.8	-1.7	7.1	-.9	2.8	-1.3	55.4	-1.2	-.8	25.0	v	-1.1
	14013.	81.	7-2	1500.	240.	16.1	2.61	2.42	.19	-.2	4.9	-1.4	8.0	-.7	4.2	-1.2	65.3	-1.2	-.8	25.0	v	-1.1
A35	14011.	32.	5-28	800.	230.	120.0	2.73	2.49	.24	4.1	6.3	3.1	7.3	3.7	4.0	3.3	11.4	3.4	3.7	2.0	n	4.4
	14011.	33.	5-28	1500.	200.	120.0	2.46	2.05	.41	4.3	6.2	3.2	6.8	4.1	4.7	3.6	12.8	3.8	4.0	1.97	n	4.4
	14011.	34.	5-29	800.	240.	120.0	2.05	1.85	.20	4.1	5.4	3.1	5.4	4.0	4.2	3.5	2.5	3.7	3.9	1.98	n	4.4
	14011.	35.	5-29	1500.	234.	120.0	1.82	1.62	.20	4.3	6.1	3.2	5.9	4.0	4.4	3.6	8.5	3.8	4.1	1.97	n	4.4
	14011.	36.	5-30	800.	260.	120.0	1.62	1.38	.24	6.8	9.9	5.8	11.2	6.6	7.0	6.1	27.0	6.1	6.2	1.88	n	7.2
	14011.	37.	5-30	1500.	240.	100.4	1.36	.970	.39	7.3	25.3	6.2	30.3	7.2	14.7	6.7	64.9	6.8	7.3	1.85	n	7.2
	14011.	38.	5-31	800.	260.	80.2	.88	.600	.28	7.4	18.9	6.3	23.9	7.2	12.9	6.7	68.9	6.8	7.6	1.85	n	7.2
	14011.	39.	5-31	1500.	270.	120.0	2.15	1.64	.51	7.4	10.7	6.5	11.4	7.2	7.8	7.1	16.4	6.6	7.1	1.85	n	7.2
	14011.	40.	6-3	800.	220.	120.0	1.58	.138	.20	7.4	8.7	6.2	8.6	7.1	7.6	6.8	7.8	6.7	6.7	1.84	n	7.2
	14011.	41.	6-3	1500.	209.	45.4	2.54	2.27	.27	11.7	20.9	9.8	24.7	11.0	16.1	9.6	69.1	10.2	11.3	1.72	n	10.0
	14011.	42.	6-4	800.	257.	78.9	2.24	1.88	.36	9.9	23.4	8.8	28.6	9.7	16.7	9.2	73.1	9.4	11.9	1.75	n	10.0
	14011.	43.	6-4	1500.	232.	120.0	1.76	1.55	.21	.2	6.6	-.7	4.6	-.2	2.1	-.7	60.4	-.7	-.6	2.2	v	-1.1
	14011.	44.	6-5	800.	234.	120.0	2.68	.000	.00	-.5	6.3	-1.9	3.2	-1.1	1.0	-1.6	52.8	-1.7	-.3	2.25	v	-1.1
B35	14014.	45.	6-5	1500.	230.	40.3	2.82	2.48	.34	.4	10.0	-.6	13.7	0.0	6.4	-1.4	70.6	-.8	0.0	24.8	v	-1.1
	14014.	46.	6-6	800.	240.	31.3	2.46	2.13	.33	-.4	10.6	-1.3	14.0	-.8	6.1	-1.7	72.3	-1.6	.1	27.0	v	-1.1
	14014.	47.	6-6	1500.	230.	44.5	2.16	1.86	.30	.2	8.6	-.7	12.0	-.6	5.8	-.9	69.8	-.4	.1	26.0	v	-1.1
	14014.	49.	6-7	1500.	266.	37.5	1.72	1.48	.24	-3.2	6.6	-3.7	11.1	-3.3	3.2	-4.1	66.0	-3.3	-2.7	30.0	v	-3.9
	14014.	50.	6-10	600.	280.	120.0	1.25	1.08	.17	-5.0	-1.8	-5.1	-2.2	-5.0	-3.8	-4.6	11.1	[illegible]	-4.3	32.0	v	-3.9
	14014.	53.	6-11	1500.	220.	90.5	2.55	2.22	.33	-3.8	4.6	-4.2	9.6	-3.8	1.6	-4.0	69.8	-4.4	-3.3	31.0	v	-3.9
	14014.	54.	6-12	1500.	280.	119.0	2.15	1.76	.39	-3.6	5.7	-4.3	8.7	-3.8	2.3	-4.7	66.6	-4.6	-3.2	32.0	v	-3.9
	14014.	56.	6-14	930.	280.	40.0	1.72	1.51	.21	4.2	11.8	3.2	14.5	4.2	9.7	3.9	68.6	4.0	4.8	20.0	n	4.4
	14014.	57.	6-14	1530.	260.	32.6	1.51	1.27	.24	5.1	11.1	4.1	13.2	4.8	9.8	4.2	68.3	4.3	4.7	19.8	n	4.4
	14014.	58.	6-17	800.	297.	34.0	1.26	1.05	.21	4.9	10.0	3.7	12.7	4.6	10.1	3.9	68.1	3.9	4.2	20.0	n	4.4
A30	14012.	59.	6-17	1500.	259.	120.0	2.46	2.33	.13	5.4	6.8	4.4	7.1	5.3	5.6	4.6	1.7	4.5	4.3	1.70	n	4.4
	14012.	60.	6-18	600.	240.	120.0	2.26	2.12	.14	4.9	6.1	3.4	5.5	4.6	4.8	4.3	7	4.2	4.2	1.71	n	4.4
	14012.	61.	6-18	1500.	239.	120.0	1.97	1.81	.16	5.2	6.4	4.0	5.4	4.6	4.8	4.0	8	4.1	4.1	1.71	n	4.4
	14012.	62.	6-19	800.	250.	120.0	1.29	.950	.34	0.0	5.5	-1.1	4.4	-.5	1.4	-1.0	39.8	-.9	-.8	1.87	v	-1.1
	14012.	63.	6-19	1500.	298.	120.0	.77	.560	.21	.4	1.8	-.6	1.8	.2	.9	-.6	-2.7	-.2	.8	1.85	v	-1.1
	14012.	64.	6-20	800.	254.	120.0	2.66	2.47	.19	6.6	7.9	5.2	9.2	6.6	7.2	[illegible]	7.7	6.2	6.7	1.65	n	7.2
	14012.	65.	6-20	1500.	251.	120.0	2.34	2.09	.25	8.1	9.3	7.1	9.4	7.9	8.2	7.2	5.0	7.4	7.4	1.61	n	7.2
	14012.	66.	6-21	800.	260.	120.0	1.83	1.55	.28	7.9	9.1	6.8	9.1	7.7	8.1	7.2	4.2	7.2	7.3	1.61	n	7.2
B30	14015.	67.	6-21	1500.	258.	100.2	3.28	2.93	.35	8.6	16.8	6.7	16.8	8.2	11.3	7.2	65.3	7.6	8.4	18.0	n	7.2
	14015.	68.	6-24	800.	298.	69.7	2.93	2.52	.41	7.9	14.7	6.7	15.8	7.7	11.5	7.0	72.6	7.2	8.1	18.2	n	7.2
	14015.	69.	6-24	1500.	246.	60.3	2.52	2.17	.35	9.2	14.7	7.2	15.9	9.0	12.6	7.3	77.4	7.6	9.3	18.0	n	7.2
	14015.	70.	6-25	1000.	240.	120.0	2.11	1.91	.20	4.9	7.9	1.7	6.4	4.7	5.3	4.1	19.4	4.3	4.4	21.0	n	4.4
	14015.	71.	6-25	1500.	240.	120.0	1.91	1.76	.15	4.7	7.8	3.7	7.7	4.6	4.8	[illegible]	22.6	4.1	4.1	21.1	n	4.4
	14015.	72.	6-26	800.	249.	120.0	1.56	1.33	.23	4.6	6.3	3.4	6.5	4.2	4.7	3.6	14.4	3.7	3.9	21.5	n	4.4
	14015.	73.	6-26	1500.	250.	59.8	2.82	2.45	.37	4.6	11.6	3.8	13.3	4.5	8.2	4.0	68.9	4.1	4.8	21.1	v	4.4
	14015.	74.	6-27	800.	237.	120.0	2.43	2.10	.33	-.2	.9	-1.5	.8	-.7	-.2	-1.3	5	-1.1	-.9	27.2	v	-1.1
	14015.	75.	6-27	1500.	240.	120.0	2.10	1.81	.29	.4	2.9	-.3	3.4	.2	.4	-.3	9.7	.1	.4	25.8	v	-1.1
	14015.	76.	6-28	800.	246.	120.0	1.40	1.21	.19	-.4	.8	-1.4	.5	-.9	-.6	-1.7	-3.3	-1.2	-1.3	27.5	v	-1.1

*120 sec recorded as a "no start" test.

†Kinematic viscosity at fuel test temperature estimated from ASTM viscosity-temperature chart.

TABLE B-2. Cold-Start Tests With LDT-465-1C Engine

Fuel	AL No	Test No	Date	Time	Cranking Speed, rpm	Sec. to Start*	Fuel wt Before, kg	Fuel wt After, kg	Fuel Used, kg	Water In Before, °C	Water In After, °C	Oil Sump Before, °C	Oil Sump After, °C	Manifold Before, °C	Manifold After, °C	Exhaust Before, °C	Exhaust After, °C	Fuel Before, °C	Fuel After, °C	Kinematic Vis, cSt†	Starting Aids	Set Temp. °C
Referee	13998.	1.	7-10	800.	240.	6.5	2.62	2.54	.08	2.3	5.9	2.7	5.2	.9	.2	1.1	71.6	1.3	1.6	5.20	n	1.7
	13998.	2.	7-10	1500.	240.	2.2	2.59	2.45	.14	2.3	4.9	1.2	3.6	1.0	.7	1.2	71.2	1.1	1.3	5.30	n	1.7
	13998	57	8-19	1500.	209.	54.3	2.36	2.22	.14	-17.	-17.	-8.6	-3.5	-18.	-17.	-17	97.2	-17.	-16.	10.0	n	-18.
	13998.	58	8-20	800.	193	120.0	2.21	2.14	.07	-19.	-19	-17.	-17	-20.	-20.	-18	-22.4	-18.	-18.	10.5	n	-18.
	13998.	59.	8-20	1500.	190.	120.0	1.84	1.76	.08	-17	-17.	-14	-14	-17.	-17	-16.	-19.7	-16.	-16.	9.80	n	-18.
A40	14010.	3.	7-11	800.	248.	2.5	2.61	2.58	.03	2.2	4.4	1.3	3.5	0.0	.6	1.0	66.7	1.0	1.2	2.08	n	1.7
	14010	4.	7-11	1500.	0.	1.5	2.55	2.50	.05	2.2	4.3	1.2	3.4	.6	.9	1.3	72.6	1.1	1.3	2.08	n	1.7
	14010.	5.	7-12	800.	244.	11.9	2.44	2.38	.06	-2.9	1.0	-4.1	-.6	-4.3	-4.4	-3.9	77.1	-4.1	-3.7	2.31	n	-4.4
	14010.	6	7-12	1500.	244.	14.3	2.34	2.26	.08	-3.3	1.1	-3.6	0.0	-5.2	-5.3	-4.3	78.7	-4.4	-3.9	2.32	n	-4.4
	14010	7	7-15	1500.	224.	9.7	2.07	1.99	.08	-4.4	-4.4	-3.2	-.5	-4.2	-4.3	-4.3	73.7	-4.1	-4.3	2.31	n	-4.4
	14010	8	7-16	800.	276.	11.5	1.92	1.85	.07	-5.0	-5.0	-4.2	-.8	-6.0	-5.4	-4.8	80.9	-4.4	-4.3	2.32	n	-4.4
	14010.	9.	7-16	1500.	221.	75.8	1.81	1.68	.13	-9.6	-9.4	-6.9	-5.1	-10.	-10.	-9.3	79.8	-9.2	-9.1	2.56	v	-9.4
	14010.	10.	7-17	800.	209.	54.7	1.67	1.48	.19	-9.8	-9.9	-9.0	-5.2	-11.	-9.9	-9.7	83.2	-9.4	-9.3	2.58	y	-9.4
	14010.	11.	7-17	1500.	189.	51.4	1.45	1.30	.15	-9.3	-9.6	-7.4	-5.6	-9.2	-9.0	-9.2	80.6	-9.1	-9.1	2.55	v	-9.4
	14010.	47.	8-12	1300.	204.	120.0	2.07	2.07	.00	-17.	-17.	-15.	-15.	-17.	-17.	-16.	-7.7	-16.	-16.	3.01	y	-18.
	14010.	49.	8-13	800.	210.	120.0	1.92	1.92	.00	-17.	-17.	-16.	-16.	-17.	-18.	-16.	-20.0	-17.	-17.	3.02	y	-18.
B40	14013.	12.	7-18	600.	185.	120.0	3.11	3.04	.07	-10.	-10.	-8.5	-8.4	-9.7	-11.	-9.5	-5.4	-9.2	-9.4	37.5	v	-9.4
	14013.	13.	7-18	1500.	188.	120.0	2.67	2.59	.08	-9.6	-9.6	-7.7	-7.5	-9.8	-9.8	-8.8	-6.7	-9.2	-9.0	37.5	v	-9.4
	14013.	14.	7-19	800.	254.	36.5	2.58	2.41	.17	-4.3	-4.3	-3.9	.8	-3.9	-4.1	-3.8	91.2	-3.7	-3.3	28.8	n	-3.9
	14013.	15.	7-19	1500.	244.	51.8	2.41	2.25	.16	-4.4	-4.3	-2.8	0.0	-4.2	-3.7	-3.9	89.2	-3.7	-3.4	28.8	n	-3.9
	14013.	16.	7-22	800.	255.	28.8	2.22	2.11	.11	.6	4	1.2	5.6	-.1	-.1	.8	78.0	1.1	1.2	22.7	n	1.7
	14013.	17.	7-22	1500.	219.	14.9	2.10	2.01	.09	.6	.7	1.6	5.3	1.2	1.0	1.0	88.2	1.1	1.3	22.7	n	1.7
	14013.	42.	8-8	600.	224.	95.7	2.59	2.42	.17	-9.1	-9.0	-7.4	-5.6	-9.3	-9.7	-8.8	79.4	-8.6	-8.6	36.8	y	-9.4
	14013.	43.	8-8	1500.	186.	104.2	2.41	2.24	.17	-8.1	-8.2	-7.7	-5.3	-8.8	-9.0	-8.4	83.2	-8.6	-8.0	36.8	y	-9.4
	14013.	44.	8-9	800.	191.	120.0	2.19	2.13	.06	-17.	-17.	-16.	-15.	-17.	-17.	-17.	-20.6	-17.	-17.	60.0	y	-18.
	14013.	45.	8-9	1500.	181.	120.0	1.88	1.82	.06	-16.	-16.	-14.	-14.	-17.	-17.	-16.	-18.8	-16.	-16.	57.0	y	-18.
A35	14011.	18.	7-23	600.	245.	5.7	2.29	2.15	.14	.6	.8	1.8	4.8	0.0	.3	1.1	81.4	.8	1.1	2.12	n	1.7
	14011.	19.	7-23	1500.	228.	2.0	2.15	2.05	.10	.8	.7	1.4	2.5	.2	.8	1.3	75.7	.3	1.0	2.12	n	1.7
	14011.	20.	7-24	800.	248.	5.6	2.01	1.89	.12	-1.9	-1.9	-1.6	.7	-2.4	-2.5	-1.8	79.4	-1.8	-1.6	2.23	n	-3.9
	14011.	21.	7-24	1500.	224.	12.0	1.87	1.76	.11	-2.7	-2.6	-2.3	-.7	-2.7	-3.0	-3.0	77.7	-3.1	-2.8	2.32	n	-3.9
	14011.	22.	7-25	815.	201.	60.2	1.71	1.53	.18	-9.8	-9.8	-9.2	-6.2	-9.8	-9.9	-9.5	81.6	-9.6	-9.2	2.70	v	-9.4
	14011.	23.	7-25	1500.	201.	80.5	1.51	1.37	.14	-9.3	-9.2	-8.7	-7.2	-10.	-9.3	-9.5	77.1	-9.5	-9.3	2.70	v	-9.4
	14011.	49.	8-13	1500.	192.	120.0	2.53	2.53	.00	-16.	-16.	-10.	-11.	-17.	-17.	-16.	-19.8	-16.	-16.	3.30	v	-18.
	14011.	50.	8-14	800.	204.	120.0	2.53	2.51	.02	-17.	-18.	-16.	-17.	-17.	-18.	-18.	-21.8	-18.	-18	3.40	y	-18.
B35	14014.	24.	7-26	800.	226.	94.9	2.44	2.28	.16	-9.4	-9.4	-8.8	-5.1	-10.	-9.8	-9.7	89.0	-9.6	-9.1	43.0	v	-9.4
	14014.	25.	7-26	1500.	212.	80.7	2.27	2.11	.16	-8.6	-8.6	-8.3	-5.7	-10.	-9.4	-9.3	87.9	-9.6	-9.2	43.0	y	-9.4
	14014.	26.	7-29	600.	209.	38.5	2.13	2.02	.11	-5.1	-5.0	-4.6	-2.6	-5.9	-5.8	-4.4	72.4	-4.6	-4.3	32.0	n	-3.9
	14014.	27.	7-29	1500.	223.	34.6	2.01	1.89	.12	-4.3	-4.2	-4.4	-2.2	-4.7	-4.4	-4.5	81.7	-4.6	-4.1	32.0	n	-3.9
	14014.	28.	7-30	800.	231.	8.4	1.90	1.80	.10	1.2	1.1	1.2	3.3	.6	.9	1.3	88.3	1.2	1.6	22.7	n	1.7
	14014.	29.	7-30	1500.	234.	9.4	1.79	1.71	.08	1.2	1.1	1.6	2.6	.8	1.2	1.6	76.1	1.4	1.8	22.5	n	1.7
	14014.	53.	8-15	1500.	189.	120.0	2.29	2.29	.00	-17.	-17.	-9.9	-11.	-18.	-19.	-17.	-10.3	-16.	-16.	68.0	y	-18.
	14014.	54.	8-16	800.	197.	120.0	2.15	2.07	.08	-18.	-18.	-17.	-17.	-18.	-19.	-17.	-9.0	-18.	-17.	77.0	y	-18.
A30	14012.	30.	7-31	600.	248.	8.8	2.54	2.44	.10	1.1	1.3	2.2	3.8	1.0	.9	1.5	80.1	1.4	1.7	1.80	n	1.7
	14012.	31.	7-31	1500.	242.	2.7	2.47	2.37	.10	1.2	1.2	1.7	2.9	-.3	0.0	1.6	72.2	1.4	1.6	1.80	n	1.7
	14012.	32.	8-1	600.	242.	19.5	2.39	2.26	.13	-2.8	-2.8	-2.4	-.7	-4.8	-3.2	-2.6	71.1	-2.6	-2.3	1.95	n	-3.9
	14012.	33	8-1	1500.	254.	7.3	2.26	2.12	.13	-2.4	-2.2	-2.2	-.6	-3.1	-3.2	-2.5	80.3	-2.4	-2.1	1.94	n	-3.9
	14012.	34.	8-2	800.	215.	60.4	2.08	1.86	.16	-9.2	-9.2	-8.4	-5.7	-10.	-11.	-9.1	82.3	-8.8	-8.7	2.21	v	-9.4
	14012.	35.	8-2	1500.	212.	82.9	1.84	1.63	.21	-8.4	-8.5	-8.0	-4.4	-9.4	-9.8	-8.8	72.6	-8.8	-8.4	2.21	v	-9.4
	14012.	51.	8-14	1500.	194.	120.0	2.26	2.25	.01	-14.	-14.	-10.	-10.	-17.	-17.	-17	-20.3	-17.	-16.	2.63	v	-18.
	14012.	52.	8-15	600.	183.	120.0	2.23	2.19	.04	-17.	-18.	-17.	-17.	-18.	-19.	-18.	-22.2	-19.	-19.	2.73	v	-18.
B30	14015.	36.	8-5	800.	211.	120.0	2.52	2.44	.08	-9.0	-9.1	-8.9	-8.5	-9.7	-8.9	-8.9	-5.9	-8.8	-8.3	42.0	y	-9.4
	14015.	37.	8-5	1500.	198.	120.0	2.43	2.35	.08	-8.6	-8.6	-8.8	-8.3	-9.3	-8.8	-9.6	-10.6	-8.8	-8.8	42.0	v	-9.4
	14015.	38.	8-6	800.	219.	90.4	2.35	2.14	.21	-3.8	-3.9	-3.7	-.6	-3.8	-4.1	-3.3	95.0	-3.4	-3.1	31.3	n	-3.9
	14015.	39.	8-6	1500.	206.	96.9	2.13	1.91	.22	-3.0	-2.9	-2.4	-.1	-3.8	-3.3	-3.2	95.0	-3.3	-2.8	31.3	n	-3.9
	14015.	40.	8-7	800.	225.	26.5	1.89	1.79	.10	2.1	2.0	2.2	3.4	1.6	1.9	2.2	79.8	2.1	2.3	23.0	n	1.7
	14015.	41.	8-7	1500.	220.	29.0	1.77	1.68	.09	1.9	1.9	2.0	2.9	2.1	1.8	2.2	79.1	2.1	2.3	23.0	n	1.7
	14015.	55.	8-16	1500.	187.	120.0	2.52	2.45	.07	-17.	-17.	-9.2	-11.	-18.	-18.	-17.	-21.4	-17	-17.	73.5	v	-18.
	14015.	56.	8-19	800.	215.	120.0	2.43	2.37	.06	-19.	-19.	-17.	-17.	-21.	-20.	-18.	-23.1	-19	-19.	85.0	y	-18.

*120 sec recorded as a "no start" test.
†Kinematic viscosity at fuel test temperature estimated from ASTM viscosity-temperature chart.

TABLE B-3. Cold-Start Tests With NHC-250 Engine

Fuel	AL No	Test No	Date	Time	Cranking Speed, rpm	Sec. to Start*	Fuel wt Before, kg	Fuel wt After, kg	Fuel Used, kg	Water In Before, °C	Water In After, °C	Oil Sump Before, °C	Oil Sump After, °C	Manifold Before, °C	Manifold After, °C	Exhaust Before, °C	Exhaust After, °C	Fuel Before, °C	Fuel After, °C	Kinematic Vis, cSt†	Starting Aid	Set Temp, °C
Referee	13998.	1.	8-26	800.	198.	40.0	2.17	1.94	.23	-.4	-.3	-.1	-.6	-.4	0.0	-.4	60.9	.2	.4	5.4	n.	1.7
	13998.	2.	8-26	1500.	207.	27.0	1.83	1.32	.51	1.6	1.7	1.4	1.7	1.4	2.1	2.4	64.1	2.2	2.4	5.1	n.	1.7
	13998.	3.	8-27	800.	236.	7.0	3.42	3.26	.16	-1.4	3.4	-3.8	-3.8	-4.6	-3.7	-.7	71.5	-3.4	-3.4	6.1	y.	-3.9
	13998.	4.	8-27	1500.	179.	51.6	2.23	3.02	.21	-6.5	-2.2	-3.5	-3.6	-3.9	-2.7	-3.3	80.2	-3.5	-3.1	6.1	y.	-3.9
	13998.	5.	8-28	800.	227.	72.2	2.99	2.75	.24	-1.6	2.8	-3.8	-4.1	-5.3	-4.6	-3.2	73.0	-3.8	-3.6	6.2	y.	-3.9
	13998.	6.	8-28	1500.	159.	120.0	2.67	2.43	.24	-2.9	-4.3	-8.8	-5.4	-9.1	-8.9	-8.1	-9.9	-9.8	-8.6	7.2	y.	-9.4
	13998.	7.	8-29	800.	151.	120.0	2.42	2.19	.23	-6.9	-6.1	-9.3	-9.4	-10.	-10.	-8.6	-11.1	-9.2	-9.1	7.3	y.	-9.4
	13998.	8.	8-29	1500.	253.	75.9	2.19	1.66	.53	-5.0	4.8	-6.4	-5.4	-9.4	-7.6	-6.1	69.4	-8.4	-5.5	7.2	y.	-9.4
	13998.	9.	8-30	800.	218.	47.2	1.44	.53	.96	-7.0	-2.5	-9.1	-9.3	-10.	-7.7	-8.8	98.3	-9.3	-7.3	7.3	y.	-9.4
A40	14010.	10.	8-30	1500.	224.	7.8	2.89	2.48	.41	-5.1	.4	-6.2	-5.9	-9.1	-7.1	-7.7	88.5	-8.6	-6.9	2.52	y.	-9.4
	14010.	11.	9-3	1500.	184.	120.0	2.43	2.25	.18	-6.4	-5.3	-8.6	-8.6	-9.7	-9.3	-7.1	-1.3	-8.8	-8.7	2.54	y.	-9.4
	14010.	12.	9-9	800.	215.	3.3	2.89	2.64	.25	-3.4	1.7	-5.9	-5.8	-4.1	-3.8	-3.9	86.5	-5.0	-4.2	2.35	y.	-3.9
	14010.	13.	9-9	1500.	235.	2.0	2.67	2.44	.23	-1.6	3.2	-3.9	-3.6	-4.2	-3.8	-3.2	92.3	-3.4	-2.7	2.28	y.	-3.9
	14010.	14.	9-10	1300.	235.	2.6	2.40	1.94	.46	-5.7	4.7	-7.6	-6.8	-9.7	-8.4	-8.1	99.4	-8.7	-6.2	2.52	y.	-9.4
	14010.	15.	9-10	1600.	244.	24.1	1.96	1.47	.49	-5.3	2.2	-7.7	-7.3	-9.3	-9.1	-8.0	94.8	-8.6	-7.4	2.52	y.	-9.4
	14010.	16.	9-11	800.	248.	10.0	1.62	1.43	.19	3.1	6.4	1.2	1.6	1.2	2.2	1.8	82.0	1.4	2.7	2.07	n.	1.7
	14010.	17.	9-11	1115.	248.	10.3	1.35	1.29	.06	4.0	7.3	2.1	3.3	1.2	2.4	2.7	84.4	2.0	2.9	2.05	n.	1.7
	14010.	49.	11-26	800.	165.	23.0	3.16	2.66	.50	-16.	-16.	-15.	-15.	-16.	-11.	-15.	98.1	-15.	-13.	2.92	y.	-15.
	14010.	50.	11-26	1500.	234.	6.0	2.64	2.30	.34	-14.	-14.	-13.	-14	-15.	-13	-14.	85.6	-14	-12.	2.83	y.	-15.
	14010.	51.	11-27	800.	135.	120.0	2.24	2.04	.20	-21.	-21.	-21.	-21.	-21.	-20.	-21.	-9.8	-20.	-20.	3.30	y.	-21.
	14010.	52.	11-27	1500.	123.	120.0	2.04	1.87	.17	-21.	-21.	-21.	-21.	-21.	-21.	-21.	-9.8	-20.	-20.	3.30	y.	-21.
	14010.	62.	12-6	1500.	253.	6.7	2.06	1.82	.24	-18.	-7.4	-19.	-19.	-22.	-19	-20.	99.4	-21.	-17	3.40	y.	-21.
	14010.	63.	12-9	800.	254.	8.0	1.82	1.29	.53	-19.	-3.9	-21.	-14.	-22.	-17.	-20.	92.3	-21.	-15.	3.40	y.	-21.
	14010.	64.	12-9	1100.	250.	2.3	1.32	1.04	.28	-11.	-5.0	-14.	-14.	-15.	-12.	-13.	85.5	-14.	-12.	2.83	y.	-15.
	14010.	65.	12-9	1500.	258.	2.0	1.08	.69	.39	-12.	-5.1	-14.	-14.	-15.	-12.	-14.	95.4	-14.	-12.	2.83	y.	-15.
	14010.	86.	1-15	1500.	206.	120.0	3.15	2.89	.26	-15.	-14.	-18.	-18.	-19.	-20.	-19.	-20.8	-19.	-19.	3.20	y.	-21.
	14010.	87.	1-16	800.	200.	120.0	2.91	2.69	.22	-17.	-16	-20.	-20.	-20.	-19.	-19.	-21.3	-20	-19	3.30	y.	-21.
	14010.	88.	1-16	1500.	204.	4.0	3.30	3.13	.17	-3.0	4.7	-8.9	-6.2	-21.	-18.	-15.	49.0	-10.	-12.	2.60	y.	-21.
	14010.	89.	1-17	800.	249.	3.5	3.13	2.82	.31	-17.	-7.0	-19.	-20.	-20.	-17.	-19.	81.8	-20.	-18.	3.30	y.	-21.
	14010.	90.	1-17	1500.	248.	40.0	2.82	2.38	.44	-19.	-7.4	-23.	-23.	-24.	-21.	-23.	84.8	-23.	-21.	3.55	y.	-26.
	14010.	91.	1-20	800.	250.	6.0	2.28	1.60	.68	-22.	-9.6	-26.	-19.	-26.	-22.	-24.	83.2	-25.	-24.	3.80	y.	-26.
	14010.	92.	1-20	1500.	192.	37.6	1.63	1.19	.44	-22.	-14.	-25.	-25.	-26.	-22.	-25.	81.8	-26.	-24.	3.85	y.	-26.
	14010.	93.	1-21	800.	251.	7.7	2.64	2.04	.60	-22.	-6.9	-25.	-10.	-26.	-20.	-25.	91.2	-25.	-22.	3.80	y.	-26.
B40	14013.	18.	9-11	1500.	211.	27.2	3.43	3.21	.22	6.7	10.3	4.7	7.0	1.4	2.6	3.1	78.8	3.4	3.4	20.5	n.	1.7
	14013.	19.	9-12	1100.	252.	9.2	3.13	3.06	.07	7.4	10.7	5.0	6.8	1.7	2.2	3.2	75.8	3.6	3.4	20.3	n.	1.7
	14013.	20.	9-12	1500.	233.	3.3	3.02	2.84	.18	-.9	4.4	-2.1	.6	-4.3	-2.7	-2.7	92.3	-3.1	-2.8	28.0	y.	-3.9
	14013.	21.	9-13	800.	253.	3.1	2.87	2.53	.34	-1.5	4.4	-3.7	-2.4	-3.8	-3.6	-2.8	96.9	-3.3	-3.0	28.2	y.	-3.9
	14013.	22.	9-13	1115.	173.	13.3	2.54	2.30	.24	-5.3	.7	-6.9	-6.9	-9.8	-7.6	-7.9	90.2	-9.1	-7.7	36.0	y.	-9.4
	14013.	23.	9-13	1500.	233.	13.8	2.29	2.02	.27	-5.8	-.3	-7.4	-7.6	-9.4	-8.4	-7.9	98.7	-8.3	-7.2	36.2	y.	-9.4
	14013.	53.	12-2	800.	112.	120.0	2.47	2.16	.31	-20.	-21.	-20.	-20.	-21.	-21.	-20.	-14.2	-20.	-20.	75.0	y.	-21.
	14013.	54.	12-2	1300.	121.	120.0	2.17	2.16	.01	-21.	-21.	-20.	-21.	-20.	-20.	-21.	-19.6	-20.	-20.	75.0	y.	-21.
	14013.	55.	12-4	800.	252.	1.8	1.87	1.64	.23	-13.	-7.5	-15.	-15.	-15.	-14.	-14.	90.8	-14.	-12.	50.0	y.	-15.
	14013.	56.	12-4	1100.	253.	4.1	1.65	1.32	.33	-12.	-4.3	-14.	-14.	-15.	-14.	-14.	91.1	-14.	-11.	50.0	y.	-15.
	14013.	81.	1-13	800.	188.	58.1	3.46	3.03	.43	-12.	.6	-15.	-14.	-15.	-13.	-14.	83.2	-14.	-14.	50.0	y.	-15.
	14013.	82.	1-13	1500.	195.	53.7	3.03	2.77	.26	-12.	-1.3	-14.	-14.	-15.	-13.	-14.	86.9	-14.	-14.	50.0	y.	-15.
	14013.	101.	1-27	800.	237.	43.2	4.06	3.63	.43	-16.	-1.5	-20.	-19.	-20.	-18.	-19.	77.7	-19.	-17.	69.0	y.	-21.
	14013.	102.	1-27	1500.	200.	67.1	3.63	3.28	.35	-16.	-3.2	-19.	-19.	-20.	-18.	-19.	80.9	-18.	-18.	65.0	y.	-21.
A35	14011.	24.	9-16	1230.	245.	1.9	3.14	2.93	.21	0.0	2.8	-2.7	-3.2	-9.1	-9.2	-6.4	66.3	-5.3	-5.2	2.42	y.	-9.4
	14011.	25.	9-16	1530.	236.	12.2	2.95	2.60	.35	-5.3	-.4	-6.9	-5.2	-9.3	-9.2	-7.7	87.4	-8.2	-7.1	2.61	y.	-9.4
	14011.	26.	9-17	1100.	259.	6.9	2.61	2.31	.30	.7	6.2	-1.4	0.0	-4.4	-2.7	-2.6	88.7	-2.9	-1.3	2.30	y.	-3.9
	14011.	27.	9-17	1500.	226.	1.6	2.32	2.08	.24	-1.2	2.7	-2.9	-1.3	-4.6	-3.9	-3.2	73.1	-3.6	-2.7	2.36	y.	-3.9
	14011.	28.	9-18	800.	243.	27.5	2.13	1.82	.31	3.3	7.6	1.5	2.4	.8	1.2	2.2	98.0	1.8	3.3	2.05	n.	1.7
	14011.	29.	9-18	1100.	218.	28.5	1.84	1.60	.24	4.0	7.4	2.2	3.4	1.2	2.1	2.3	89.7	1.8	3.4	2.05	n.	1.7
	14011.	57.	12-4	1600.	265.	3.1	3.83	3.51	.32	-11.	-2.3	-13.	-12.	-15.	-12.	-14.	89.2	-14.	-13.	3.10	y.	-15.
	14011.	58.	12-5	800.	268.	3.9	3.55	3.36	.19	-12.	-4.7	-14.	-14.	-14.	-13.	-14.	95.9	-14.	-13.	3.10	y.	-15.
	14011.	59.	12-5	1100.	202.	13.3	3.30	2.91	.39	-17.	-7.9	-18.	-18.	-22.	-19.	-20.	90.1	-20.	-18.	3.70	y.	-21.
	14011.	60.	12-5	1600.	223.	85.6	2.93	2.43	.50	-18.	-3.2	-20.	-20.	-22.	-19.	-20.	93.6	-21.	-16.	3.80	y.	-21.
	14011.	61.	12-6	800.	255.	13.9	2.42	2.06	.36	-19.	-8.6	-21.	-21.	-21.	-19.	-20.	93.2	-21.	-18.	3.80	y.	-21.
B35	14014.	30.	9-18	1500.	250.	24.8	3.34	3.06	.28	5.4	9.6	3.3	5.8	1.5	2.4	2.3	98.2	2.5	3.2	21.5	n.	1.7
	14014.	31.	9-19	812.	215.	26.8	3.06	2.82	.24	3.8	7.9	1.8	3.2	1.1	2.4	2.1	90.7	1.9	2.7	22.0	n.	1.7
	14014.	32.	9-19	1100.	238.	3.6	2.79	2.55	.24	-.7	4.7	-2.1	.5	-4.2	-2.9	-3.1	88.5	-3.4	-1.5	29.0	y.	-3.9
	14014.	33.	9-19	1500.	230.	2.3	2.53	2.33	.20	-1.7	3.4	-3.2	-2.2	-4.7	-2.9	-3.2	90.2	-3.9	-.9	30.0	y.	-3.9
	14014.	34.	9-20	1500.	231.	2.7	2.31	1.99	.32	-5.2	0.0	-7.1	-6.6	-8.6	-6.0	-7.8	101.2	-8.2	-5.1	39.0	y.	-9.4
	14014.	35.	9-23	800.	234.	16.3	2.02	1.70	.32	-7.3	.3	-9.6	-9.6	-9.6	-6.2	-9.0	99.1	-9.1	-6.1	41.0	y.	-9.4
	14014.	36.	9-23	1100.	219.	2.5	1.71	1.40	.31	-5.7	-1.6	-8.1	-8.1	-9.7	-7.3	-8.7	97.6	-9.2	-7.5	42.0	y.	-9.4
	14014.	66.	12-10	800.	252.	7.5	3.42	2.88	.54	-12.	-.9	-14.	-14.	-15.	-12.	-14	93.8	-14.	-13.	58.0	y.	-15.
	14014.	67.	12-10	1100.	248.	5.8	2.89	2.53	.36	-11.	-2.2	-13.	-13.	-14.	-12.	-13.	88.3	-14.	-13.	58.0	y.	-15.
	14014.	68.	12-10	1500.	233.	27.9	2.50	2.06	.44	-18.	-5.6	-18.	-18.	-21.	-19.	-20.	92.7	-20.	-17.	90.0	y.	-21.
	14014.	69.	12-11	800.	244.	30.0	2.06	1.70	.36	-18.	-7.7	-20.	-20.	-21.	-18.	-20.	97.1	-20.	-17.	90.0	y.	-21.
A30	14012.	37.	9-23	1500.	259.	3.9	3.22	2.81	.41	2.1	8.5	-.3	2.4	-9.3	-6.8	-6.2	94.4	-5.6	-2.8	2.09	y.	-9.4
	14012.	38.	9-24	800.	232.	10.3	2.81	2.37	.44	-7.0	2.7	-9.2	-9.2	-9.9	-6.9	-8.8	95.0	-9.1	-6.9	2.22	y.	-3.4
	14012.	39.	9-24	1100.	248.	2.0	2.42	1.89	.53	-.9	9.6	-4.4	-.8	-3.7	-2.2	-3.2	105.6	-3.7	-2.4	1.98	y.	-3.9
	14012.	40.	9-24	1500.	247.	3.4	1.95	1.56	.39	-.6	5.1	-2.8	-1.6	-4.2	-.9	-3.3	100.0	-3.7	-2.3	1.93	y.	-3.9
	14012.	41.	9-25	800.	230.	60.5	1.64	1.29	.35	3.3	9.4	1.3	2.4	1.0	4.3	2.1	82.8	1.6	3.4	1.80	n.	1.7
	14012.	42.	9-25	1100.	237.	50.3	1.32	.89	.43	3.9	10.1	2.2	4.0	1.6	2.0	2.8	85.6	2.1	5.2	1.77	n.	1.7
	14012.	70.	12-11	1530.	232.	5.7	1.66	1.40	.26	-17.	-11.	-19.	-19.	-22.	-19	-19.	104.1	-20.	-18	2.90	y.	-21.
	14012.	71.	12-12	800.	248.	32.0	1.41	1.14	.27	-18.	-12	-20.	-20.	-21.	-21	-19.	99.9	-20.	-19.	2.90	y.	-21.
	14012.	72.	12-12	1100.	240.	2.7	1.14	.88	.26	-17.	-14.	-20.	-20.	-21.	-20.	-19.	103.7	-20.	-19.	2.90	y.	-21.
	14012.	83.	1-14	800.	202.	52.1	3.60	2.94	.66	-12.	.3	-14.	-15.	-15.	-14	-14.	88.9	-14.	-13	2.50	y.	-15.
	14012.	84.	1-14	1500.	214.	120.0	2.94	2.70	.24	-12.	-10	-15.	-14	-15.	-15.	-14.	-15.9	-15.	-14.	2.55	y.	-15.
	14012.	85.	1-15	800.	213.	120.0	2.60	2.36	.24	-12.	-11.	-15.	-15.	-15	-15.	-15.	-16.9	-14.	-14.	2.50	y.	-15.
	14012.	94.	1-21	1500.	260.	1.6	3.56	2.84	.72	-13.	-.3	-17.	-17.	-21	-17.	-18.	35.2	-19.	-16	2.80	y.	-21.
	14012.	95.	1-22	800.	248.	1.9	2.86	2.33	.53	-17.	-3.2	-20.	-19	-20.	-18.	-19.	80.8	-19.	-17.	2.80	y.	-21.
	14012.	96.	1-22	1500.	243.	14.7	2.32	1.81	.51	-21.	-9.9	-24.	-24.	-25.	-22.	-24.	82.3	-24.	-22.	3.20	y.	-26.
	14012.	97.	1-23	800.	241.	9.0	1.85	1.31	.54	-21.	-10.	-24.	-24	-25.	-22.	-24.	33.3	-24	-23.	3.20	y.	-26.
	14012.	98.	1-23	1500.	230.	1.6	3.37	2.91	.46	-12.	-3.8	-16.	-16.	-15.	-14.	-14.	32.0	-15	-14	2.55	y.	-15.
	14012.	99	1-24	800.	250.	1.8	2.93	2.42	.51	-12.	-2.3	-15.	-15	-15	-13.	-14.	84.9	-15	-14	2.55	y.	-15.
B30	14015	43.	9-25	1500.	247.	75.0	3.61	3.17	.44	8.0	12.9	4.6	8.4	1.5	2.5	3.4	31.2	3.9	[illegible]	21.3	n.	1.7
	14015.	44.	9-26	600	232.	120.0	3.15	2.87	.28	3.8	5.4	1.6	2.2	1.2	1.6	2.5	19.2	2.0	2.1	23.0	n.	1.7
	14015.	45.	9-26	1100.	252.	1.7	2.77	2.51	.26	0.0	4.9	-2.1	-.3	-3.1	-1.4	-2.3	102.3	-2.6	-1.6	29.5	y.	-3.9
	14015	46.	9-26	1500.	251.	15.0	2.52	2.23	.29	-.3	5.3	-3.0	-.7	-3.9	-2.0	-2.8	103.6	-3.3	-1.6	30.5	y.	-3.9
	14015	47.	9-27	800.	230.	10.7	2.22	1.77	.45	-6.8	1.1	-8.9	-5.9	-9.7	-9.3	-7.4	93.9	-8.6	-7.3	41.0	y.	-9.4
	14015.	48.	9-27	1100.	230.	12.6	1.80	1.46	.34	-5.7	.2	-7.9	-6.8	-9.7	-6.3	-6.2	87.9	-8.8	-7.9	41.3	y	-9.4
	14015	73.	12-12	1530.	260.	60.2	3.49	3.10	.39	-15.	-2.1	-17.	-16.	-21.	-18.	-19.	85.7	-19.	-16.	85.0	y.	-21.
	14015	74	12-13	800.	238.	39.3	3.11	2.72	.39	-18.	-6.0	-20.	-20.	-20.	-20.	-20.	76.6	-20.	-19.	90.0	y.	-21.
	14015	75.	12-13	1100.	256.	13.0	2.77	2.41	.36	-11.	-.6	-15.	-15.	-15	-13.	-13.	[illegible]	-14.	-12.	58.0	y.	-15.
	14015	76.	12-13	1500.	260.	15.1	2.43	2.05	.38	-11.	.4	-14.	-13.	-15.	-14.	-13.	94.4	-14.	-12.	58.0	y.	-15.
	14015	77.	12-17	800.	187.	108.5	2.43	1.73	.73	-22.	-4.4	-25.	-25.	-26.	-22.	-24.	92.1	-24.	-20.	121	y.	-26.
	14015	78.	12-17	1500.	160.	120.0	1.45	1.27	.18	-24.	-19.	-25.	-25.	-27.	-26.	-25.	[illegible]	-26.	-26.	150	y.	-26.
	14015	79.	12-18	800.	146.	120.0	1.29	1.12	.17	-22.	-21.	-25.	-25.	-26.	-25.	-24.	-23.1	-25.	-25.	130	y.	-26.
	14015	80.	12-19	1500.	136.	120.0	3.20	3.10	.10	-24.	-22.	-26.	-26.	-26.	-25.	-25.	[illegible]	-25.	-25.	130	y.	-26

*120 sec recorded as a "no start" test.

†Kinematic viscosity at fuel test temperature estimated from ASTM viscosity-temperature chart.

TABLE B-4. Cold-Start Tests With GM 6.2L Engine

	AL No	Date	Fuel wt. Before, kg	Fuel wt. After, kg	Water In Before, °C	Water In After, °C	Oil Sump Before, °C	Oil Sump After, °C	Cold Box Before, °C	Cold Box After, °C	Fuel Before, °C	Fuel After, °C	Exhaust Before, °C	Exhaust After, °C	Manifold Before, °C	Manifold After, °C	Cranking Speed, rpm	Start?	Sec. to Start*	Starting Aid
A40	4010.	5-14	14.22	13.87	-10.	-5.6	-9.4	-10.	-11.	-11.	-11.	-10.6	-10.	39.4	-11.	-9.4	210.	Y.	3.6	Y
	4010.	5-14	14.07	13.74	-13.	-12.	-12.	-12.	-13.	-14.	-13.	-12.8	-12.	22.6	-12.	-14	196.	Y	5.4	Y.
	4010.	5-15	13.85	13.53	-12.	-7.2	-12.	-12.	-12.	-11.	-12.	-12.2	-11.	28.3	-12.	-10.	246.	Y.	5.4	Y.
	4010.	5-15	13.69	13.48	-18.	-16.	-19.	-16.	-19.	-18.	-18.	-17.8	-16.	20.0	-17.	-18.	196.	Y.	7.2	Y.
	4010.	5-18	13.50	13.16	-18.	-17.	-17.	-18.	-17	-19.	-19.	-18.3	-16.	52.3	-18.	-17.	193.	Y.	5.4	Y.
	4010.	5-18	13.36	13.05	-23.	-22.	-21.	-21.	-24.	-22.	-23.	-22.8	-20.	28.9	-22.	-21.	196.	Y	6.4	Y
	4010.	5-20	14.58	14.32	-22.	-22.	-21.	-21.	-23.	-22.	-23.	-22.8	-20.	17.8	-22.	-21	190.	Y	9.6	Y
	4010.	5-21	14.57	14.22	-29.	-28.	-28.	-27.	-30.	-31.	-30.	-30.0	-29.	3.9	-30.	-30	155.	Y	88.	Y.
	4010.	5-21	14.39	14.10	-31.	-31.	-29.	-29.	-32.	-32.	-31.	-31.7	-29.	-15.6	-31.	-31.	154.	N.	90	Y
	4010.	5-21	14.26	13.80	-29.	-28.	-28.	-28.	-30.	-31.	-29.	-29.4	-28.	22.8	-29.	-29	165.	Y	99.	Y
A36	4011.	5-21	15.10	14.88	-29.	-27.	-25.	-26.	-31	-31	-29.	-29.4	-29.	-3.3	-29	-29	154	N	90.	Y
	4011.	5-22	14.98	14.79	-29.	-27.	-29.	-28.	-29.	-28.	-30.	-30.0	-29.	-8.3	-29.	-29.	150.	N.	90.	Y
	4011.	5-22	14.79	14.54	-21.	-21.	-23.	-23.	-22.	-22.	-22.	-22.2	-21.	3.3	-21.	-21.	198.	Y.	26.	Y.
	4011.	5-25	14.52	14.26	-23.	-22.	-22.	-22.	-24.	-24.	-23.	-23.3	-21.	26.1	-23	-23.	131.	Y	22.	Y.
	4011.	5-25	14.15	13.84	-16.	-16.	-17.	-17.	-18.	-18.	-17	-17.2	-16.	24.4	-17	-17	197.	Y	7.2	Y
	4011.	5-26	14.04	14.03	-16.	-16.	-16.	-15.	-18.	-18.	-17.	-17.2	-15.	51.7	-17.	-17.	204.	Y.	12.	Y.
	4011.	5-26	13.98	13.90	-16.	-16.	-15.	-15.	-17.	-17.	-17.	-16.7	-14.	44.4	-16.	-16	199.	Y.	11.	Y
	4011.	5-27	13.81	13.67	-9.4	-9.4	-9.4	-9.4	-11	-11.	-12.	-11.7	-8.9	11.7	-11.	-10	206.	Y	5.4	Y
	4011.	5-27	13.71	13.63	-10.	-10.	-10.	-10.	-11.	-12.	-12.	-12.0	-9.4	27.8	-11.	-9.4	204.	Y	5.0	Y
A30	4012.	5-28	14.79	0.00	-14.	-12.	-14.	-14.	-14.	-15.	-14.	-14.4	-13.	2.2	-13	-11.	233.	Y.	70.	Y.
	4012.	5-28	0.00	14.36	-13.	-11.	-13.	-13.	-13.	-14.	-14.	-13.9	-13.	27.2	-13.	-12.	230.	Y	20.	Y.
	4012.	5-29	14.29	14.20	-16.	-15.	-15.	-15.	-16.	-16.	-17.	-16.1	-15.	30.0	-16.	-13.	230.	Y.	20.	Y.
	4012.	5-29	14.20	14.20	-17.	-16.	-16.	-16.	-18.	-17.	-17.	-17.8	-16.	28.9	-16.	-13	236.	Y	29.	Y.
	4012.	6-1	14.06	14.09	-22.	-18.	-21.	-21	-23.	-19.	-22.	-21.7	-22.	9.4	-22.	-19.	164.	N	90.	Y.
	4012.	6-2	14.34	14.28	-22.	-22.	-22.	-22.	-23.	-23.	-22.	-22.2	-22.	-21.7	-22.	-23.	154.	N.	90	Y
	4012.	6-2	8.07	7.88	-24.	-20.	-22.	-22.	-24.	-23.	-24.	-23.9	-23.	75.0	-23.	-22.	174.	Y	61.	Y.
	4012.	6-3	8.04	7.93	-24.	-21.	-22.	-21.	-24.	-22.	-23.	-22.8	-22.	31.1	-22.	-21.	215.	Y.	18.	Y.
	4012.	6-4	8.03	7.81	-23.	-20.	-22.	-22.	-25.	-23.	-24.	-23.9	-22.	23.3	-23.	-22.	197.	Y.	60.	Y.
	4012.	6-4	7.81	7.76	-28.	-25.	-26.	-26.	-31.	-30.	-30.	-30.0	-27.	18.9	-28.	-27.	190.	N.	90.	Y.
	4012.	6-5	7.79	7.75	-27.	-26.	-27.	-27.	-29.	-29.	-29.	-28.9	-27.	-5.6	-28.	-27.	168.	N.	90.	Y.
B40	4013.	6-10	11.15	11.11	-14.	-12.	-14.	-14.	-16.	-15.	-16.	-15.6	-14.	10.6	-15.	-14	188.	N.	90.	Y.
	4013.	6-10	11.16	11.11	-17.	-14.	-16.	-16.	-18.	-17.	-18.	-17.8	-16.	11.7	-17.	-16.	193.	N	90.	Y.
	4013.	6-11	12.06	11.91	-11.	-8.3	-8.9	-8.3	-11.	-10.	-11.	-11.1	-11.	11.1	-11.	-10.	186.	N.	90.	Y.
	4013.	6-11	11.37	10.08	-12.	-8.9	-12.	-12.	-13.	-12.	-13.	-13.3	-11.	8.3	-12.	-11.	188.	N.	90.	Y.
	4013.	6-12	12.48	12.17	-6.1	2.8	-6.1	-6.1	-6.7	-5.0	-7.2	-6.1	-6.1	47.8	-7.2	-4.4	184.	Y.	89.	Y.
	4013.	6-12	12.38	12.28	-6.7	-.6	-6.1	-6.1	-7.2	-6.1	-6.7	-6.1	-5.6	36.1	-6.1	-3.9	196.	Y.	89.	Y.
	4013.	6-25	13.91	13.72	0.0	1.1	-.6	-.6	-.6	-.6	-1.1	-1.1	-.6	38.9	-1.1	.6	203.	Y.	29.	Y.
	4013.	6-25	13.74	13.53	-.6	2.8	-.6	-.6	-1.1	-.6	-1.1	-1.1	-.6	40.0	-1.1	-1.1	205.	Y.	15	Y.
	4013.	6-26	16.34	16.02	-5.0	-.6	-5.0	1.1	-5.0	-3.9	-5.6	-4.4	-5.0	50.6	-6.7	-2.2	195.	Y.	82.	Y.
	4013.	6-26	16.50	16.38	-.6	7.8	-1.1	-.6	-.6	-.6	-1.1	-1.1	0.0	46.7	-.6	1.1	208.	Y.	21.	Y.
	4013.	6-29	16.04	15.88	-5.6	-3.3	-6.1	-6.1	-6.7	-6.7	-6.1	-6.7	-6.1	10.6	-6.7	-5.6	190.	N.	90.	Y.
	4013.	6-29	14.80	14.67	-5.6	-2.8	-4.4	-4.4	-6.1	-6.1	-6.1	-6.1	-5.6	11.7	-5.6	-5.0	175.	N.	90.	Y.
	4013.	6-30	14.66	14.52	-6.1	-2.8	-6.1	-6.1	-6.1	-7.2	-6.7	-6.7	-5.6	11.7	-7.2	-6.7	162.	N.	90.	Y.
	4013.	6-8	10.94	10.95	-27.	-25.	-28.	-27.	-28.	-29.	-28.	-27.8	-27.	-8.9	-28.	-28.	150.	N.	90.	Y.
	4013.	6-8	10.99	10.94	-28.	-26.	-28.	-28.	-31.	-30.	-30.	-28.9	-27.	-16.7	-29.	-28.	150.	N.	90.	Y.
	4013.	6-9	10.88	10.81	-23.	-21.	-23.	-22.	-24.	-23.	-23.	-23.3	-21.	2.2	-23.	-23.	164.	N.	90.	Y.
	4013.	6-9	10.94	10.94	-22.	-22.	-22.	-22.	-23.	-24.	-23.	-23.3	-21.	3.9	-23.	-22.	156.	N.	90.	Y.
B35	4014.	6-15	13.42	13.38	-6.7	0.0	-6.7	-6.1	-7.8	-7.2	-7.8	-7.8	-6.1	32.8	-6.1	-5.6	186.	Y.	87.	Y
	4014.	6-16	8.38	8.39	-6.7	-5.6	-6.7	-6.1	-6.1	-5.6	-6.7	-7.2	-6.1	39.4	-6.7	-5.6	185.	Y.	24.	Y.
	4014.	6-16	8.48	8.27	2.2	2.8	2.8	2.8	1.7	1.7	1.7	2.2	2.8	37.8	2.2	2.8	240.	Y.	15.	Y.
	4014.	6-17	8.28	8.05	2.2	2.2	1.7	2.8	1.7	1.7	1.1	1.7	1.7	36.1	1.7	1.1	208.	Y.	16.	Y.
	4014.	6-18	13.23	13.05	-1.7	1.7	-1.1	-1.1	-2.8	-2.8	-2.2	-2.2	-1.1	34.4	-2.2	-1.7	211.	Y.	18.	Y.
	4014.	6-18	12.78	12.24	-1.1	5.6	-1.1	-.6	-1.7	-1.1	-2.2	-1.7	-1.1	50.0	-1.1	0.0	190.	Y.	86.	Y.
	4014.	6-19	11.98	11.61	-1.1	5.6	-1.7	-1.1	-2.2	-2.8	-2.2	-2.8	-1.1	50.0	-1.7	-1.7	215.	Y.	18.	Y
	4014.	6-19	11.53	11.23	-5.0	-1.7	-5.0	-5.0	-6.7	-5.6	-6.1	-6.1	-5.0	51.7	-5.6	-4.4	207.	Y.	46.	Y.
	4014.	6-22	14.79	14.68	-12.	-8.9	-11.	-11.	-12.	-13.	-12.	-12.2	-12.	15.0	-12.	-11.	174.	N.	90.	Y.
	4014.	6-22	0.00	14.83	-5.6	-2.8	-5.6	-5.6	-7.2	-6.1	-5.0	-6.1	-5.0	47.8	-5.6	-5.0	210.	Y	33.	Y.
	4014.	6-23	14.64	14.40	-11.	-8.3	-11.	-11.	-12.	-12.	-13.	-11.7	-12.	3.3	-12.	-9.4	169.	N.	90.	Y
B30	4015.	6-23	15.20	14.83	3.3	16.7	6.7	7.8	1.7	2.8	2.8	2.8	3.3	65.0	2.8	6.7	191.	Y	39.	Y
	4015.	6-24	14.65	14.51	2.2	8.3	1.7	2.2	1.7	1.7	1.7	2.2	2.2	30.0	2.2	3.3	196.	N	90.	Y
	4015.	6-24	14.95	14.62	2.2	9.4	1.7	1.7	1.7	1.7	1.7	1.7	2.2	62.8	2.2	3.9	199.	Y	84.	Y
	4015.	7-10	16.36	16.18	4.4	10.6	3.9	3.9	3.9	3.9	3.9	3.9	4.4	51.7	4.4	4.4	202.	Y	9.6	Y.
	4015.	7-10	16.16	16.00	1.7	10.8	1.7	2.2	1.7	2.2	1.7	2.8	2.2	67.2	1.7	2.8	193.	Y.	59.	Y.
	4015.	7-13	16.02	15.68	2.2	11.7	1.7	1.7	1.7	2.2	1.7	1.7	1.7	41.1	1.7	3.3	190.	Y.	84.	Y.
	4015.	7-13	15.78	15.47	0.0	5.0	-.6	0.0	-1.1	-.6	-.6	-.6	0.0	57.8	-.6	1.1	189.	Y.	52.	Y.
	4015.	7-14	15.38	15.14	-1.1	2.8	-1.7	-.6	-.6	-1.7	-1.1	-1.1	-1.1	25.6	-.6	.6	190.	N.	90.	N.
	4015.	7-14	15.46	15.30	-1.1	2.2	-1.1	-1.1	-1.7	-.6	-1.7	-.6	-1.1	30.6	-1.1	.6	191.	N.	90.	N.
	4015.	7-2	17.35	17.06	16.1	18.9	15.6	15.6	15.6	15.0	15.6	15.6	15.6	73.3	16.1	15.6	191.	Y.	3.6	Y.
	4015.	7-6	17.34	17.11	16.1	20.0	15.6	16.1	16.1	15.0	15.6	15.6	15.6	89.4	15.6	15.0	208.	Y.	3.6	Y.
	4015.	7-6	17.21	17.09	13.3	17.8	12.8	13.3	11.7	12.8	12.2	12.8	12.8	85.6	12.8	13.3	215.	Y.	5.4	Y.
	4015.	7-7	16.98	16.89	10.6	13.9	10.0	10.0	10.6	9.4	10.0	10.0	10.0	60.6	10.0	10.0	212.	Y.	14.	Y.
	4015.	7-7	17.10	17.99	12.8	14.4	12.8	12.8	12.2	11.7	12.2	12.2	12.8	52.2	12.8	12.8	215.	Y.	5.4	Y.
	4015.	7-8	16.90	16.75	10.6	16.7	10.0	10.0	9.4	9.4	9.4	10.0	10.0	70.0	9.4	10.6	216.	Y.	6.6	Y.
	4015.	7-8	16.77	16.61	7.2	12.8	7.2	7.2	7.2	6.7	6.7	7.2	7.2	51.7	7.2	7.2	212.	Y.	13.	Y.
	4015.	7-9	16.50	16.35	4.4	10.6	4.4	4.4	3.9	5.0	3.9	4.4	5.0	39.4	4.4	5.6	202.	Y.	47.	Y.
	4015.	7-9	16.71	16.54	7.2	14.4	6.7	6.7	7.2	6.7	7.2	7.2	7.2	44.4	7.2	7.2	206.	Y.	19.	Y.

*90 sec recorded as a "no start" test.

APPENDIX C

Injector Fouling Bench Test Methodology for Diesel Fuel Thermal Stability

INJECTOR FOULING BENCH TEST METHODOLOGY FOR DIESEL FUEL THERMAL STABILITY

1.0 **Scope**

1.1 This methodology is being developed for evaluating the thermal oxidative deposition/sticking and/or fouling tendencies (under accelerated test conditions) of diesel injector.

1.2 This methodology will be used to determine the tendency of diesel fuel to cause sticking and/or fouling of injector parts in service operation.

2.0 **Apparatus**

2.1 **References**

2.1.1 **CLR-Diesel Engine Manual**

2.1.2 **Detroit Diesel Series 53 Service Manual**

2.1.3 **Cummins P-T Injector System Manual**

2.1.4 **ISO 4010-1977 (E)**

2.2 **Injector Systems**

2.2.1 The injector systems used for IFBT evaluations represent the three most common injection systems used in diesel engines. The three IFBT apparatus were developed to examine the sensitivity of each unique injection system to fuel thermal stability.

2.2.1.1 The CLR-Diesel IFBT apparatus represents a jerk pump-line-nozzle type of injection system. The jerk pump meters and pressurizes the fuel, which is carried to a remote nozzle by a high pressure line. All fuel recirculation occurs in the jerk pump and the bypassed fuel does not see high injector temperatures.

The IFBT apparatus was designed to simulate the injector pintle deposition of the CLR-Diesel hot test engine. The apparatus is shown in Fig. C-1. Thermal mapping of the pintle in the CLR-Diesel engine determined the temperatures at which the injector is controlled.

2.2.1.2 The IFBT Detroit Diesel (DD) apparatus was developed to determine the injector deposition tendencies of the DD unit injector. The unit injector contains the metering/pressurizing assembly and nozzle in a single unit; thus the bypassed fuel is exposed to high injector temperatures. The interest in developing the DD rig spawned from the high fuel return rates of the unit injector in which the fuel is used to cool the injector in the cylinder head. The high recycle rate and the additional thermal stressing of the fuel are considered important factors governing the pintle deposition with the DD rig. Fig. C-2 is a schematic of the Detroit Diesel test apparatus.

2.2.1.3 The IFBT Cummins apparatus was developed to examine the relative deposition tendencies of the Cummins PT-fuel injection system. The PT-fuel system uses a low pressure/high volume pump to supply fuel to the injectors at a constant pressure dependent on load. All metering occurs through an orifice in the injector. When the injector plunger is lifted off its seat, all remaining unmetered fuel is recirculated. The bypassed fuel is used to cool the injector, where it is exposed to high temperatures. Fig. C-3 depicts the Cummins IFBT apparatus.

2.3 Preparation for Test

2.3.1 Prior to the test, the injectors for the respective bench test rigs are examined, based on the procedures outlined in their respective manuals. Additional tests include a nozzle airflow check and a TDR spun rating for baseline data of a clean pintle/plunger. The test undergoes a battery of tests listed in TABLE C-1.

TABLE C-1. Fuel Tests

JFTOT Breakpoint
ASTM D 2276
ASTM D 2274

2.4 Test Procedures

2.4.1 For each of the three IFBT rigs, 20 gallons of the test fuel is procured. The injector rigs are operated at their respective conditions described in TABLE C-2.

TABLE C-2. IFBT Operating Conditions

Condition	Bosch APE CLR-D	Detroit Diesel	Cummins
Test hours	40	40	40
Speed, rpm	1000	1000	1000
Fuel flow, gal/hr	0.5	0.5	0.5
Fuel pressure, psi	---	---	140
Fuel spray temp, °C (°F)	288 (550)	204 (400)	204 (400)

After-test performance evaluations include the evaluations described in the respective injector references, plus the air flow test for the determination of nozzle hole plugging. The air flow evaluation is a modification of the ISO 4010-1977 (E) standard.

Also, following the completion of the test, the pintle/plungers are rated for deposition by the methods listed in TABLE C-3 and compared to their respective before-test measurements. Results are then listed in the respective work sheets (Figs. C-4 through C-6).

TABLE C-3. IFBT Deposition ratings

Visual CRC lacquer demerit scale
TDR spun rating
Dielectric breakdown
JFTOT visual rating scale

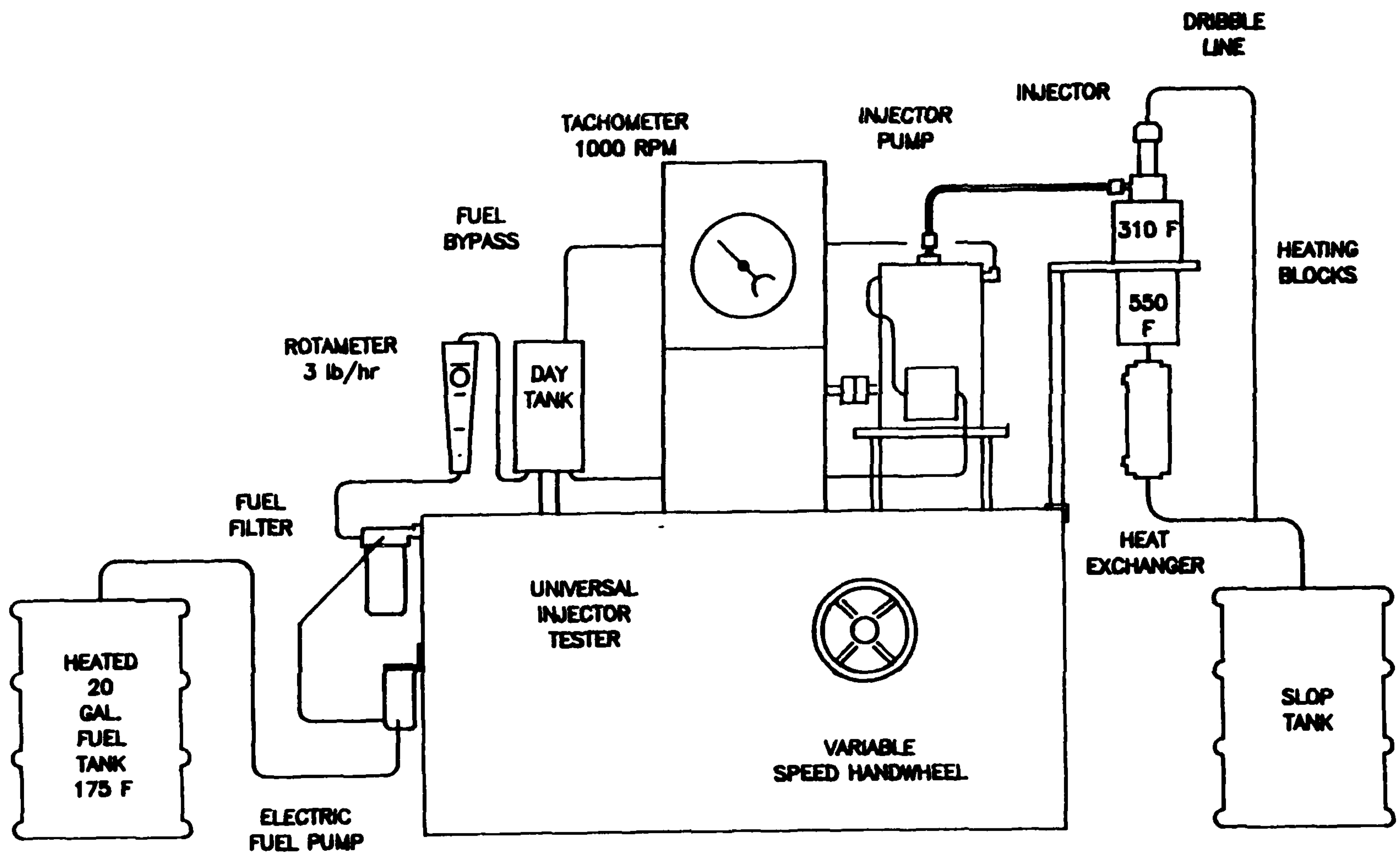


Figure C-1. CLR-D injector fouling bench test apparatus

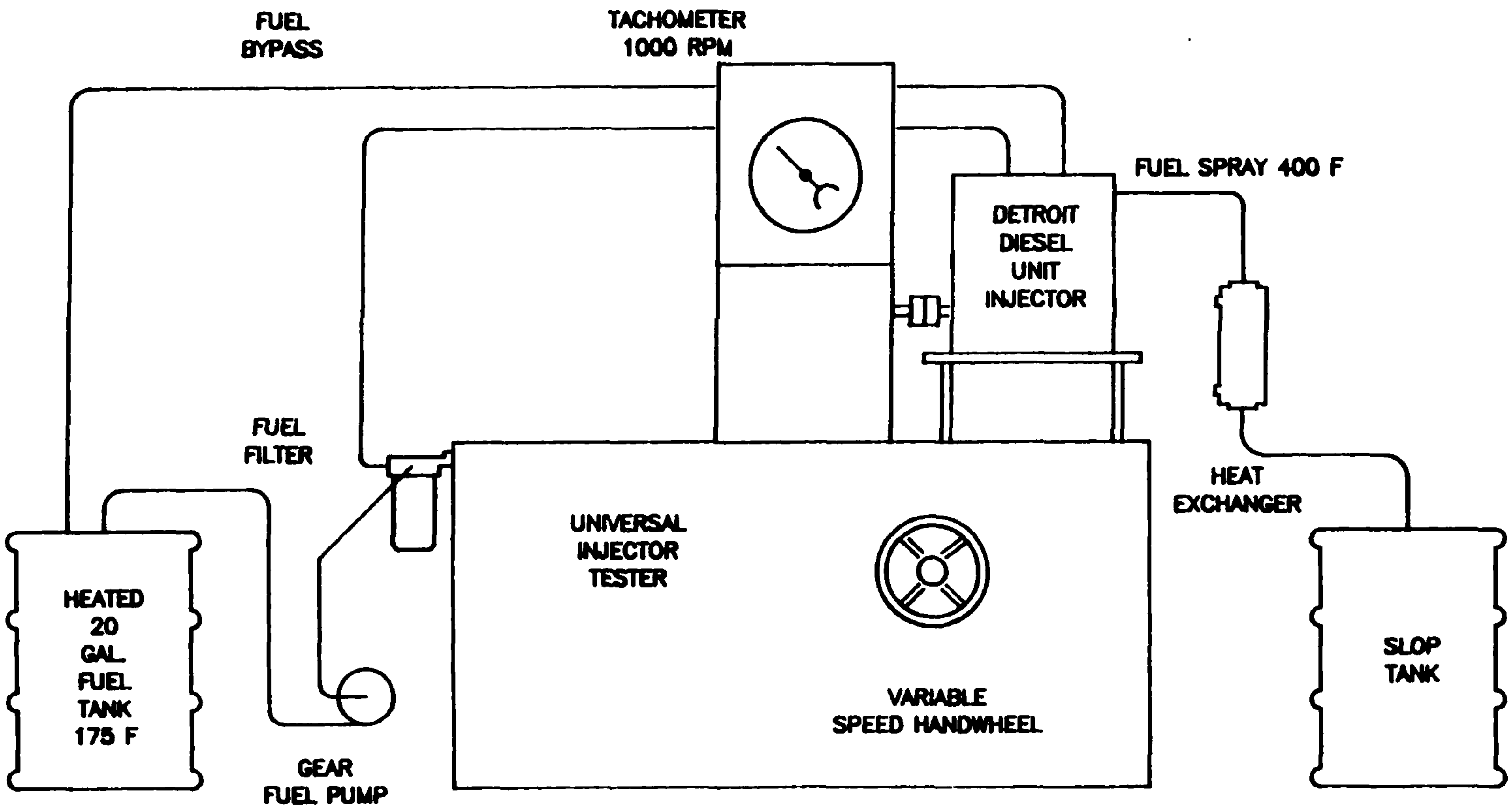


Figure C-2. Detroit Diesel injector fouling bench test apparatus

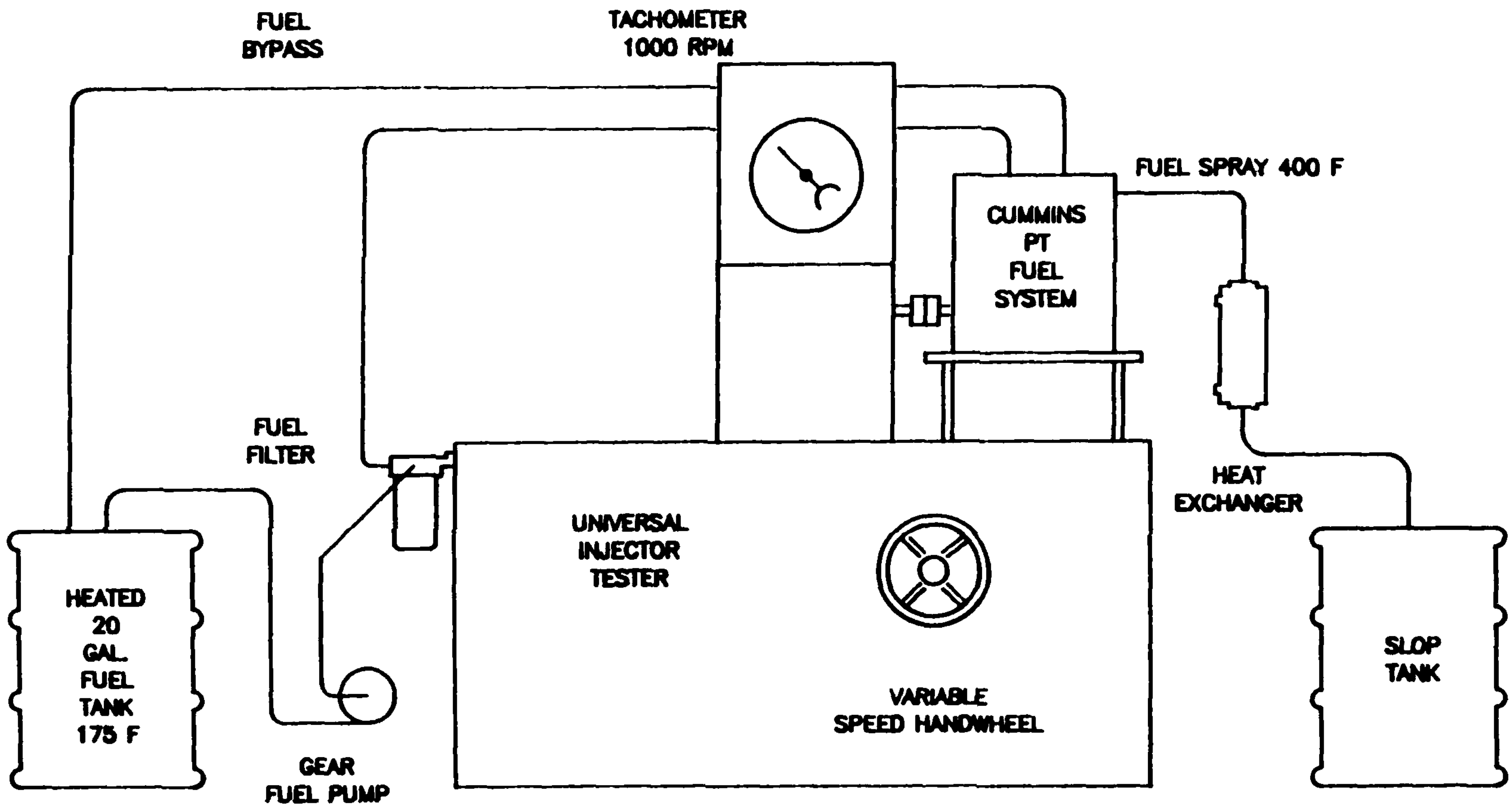


Figure C-3. Cummins injector fouling fouling bench test apparatus

APPENDIX D

Diesel Fuel Specification Comparisons

APPENDIX D

Diesel Fuel Specification Comparisons

ASTM ES-XX-XX, Emergency 2-D Specification is to be held in abeyance at ASTM headquarters, to be used in the event of an emergency.

TABLE D-1 compares the physical and chemical requirements for VV-F-800D, ASTM ES-XX-XX (Emergency 2-D) and VV-F-XXX, example--Variable Quality Diesel Fuel specifications.

TABLE D-1. Physical and Chemical Requirements for VV-F-800, ASTM ES-XX-XX, and Variable Quality Diesel Fuel

Properties	VV-F-800D Values				ASTM ES-XX-XX Emergency 2-D	VV-F-XXX Variable Quality Diesel Fuel
	Grade DF-A	Grade DF-1	Grade DF-2			Ambient at or above 45°F
			CONUS	OCONUS		
Density, kg/L at 15°C	Report	Report	Report	0.815 to 0.860	--	0.78 to 0.89
Flash Point, °C, min	38	38	52	56 1/	38	38
Cloud Point, °C, max	-51	2/	2/	2/	Local	7°C (45°F)
Pour Point, °C, max	Report	Report	Report	3/	--	--
K. Vis. at 20°C, cSt	--	--	--	1.8 to 9.5	--	--
K. Vis. at 40°C, cSt	1.1 to 2.4	1.3 to 2.9	1.9 to 4.4	(1.4 to 5.5)	1.7 to 4.3	1.3 to 5.5
Distillation, °C,						
50% evaporated	Report	Report	Report	Report	--	Report
90% evaporated, max	288	288	338	357	360	360
End Point, max	300	330	370	370	--	385
Residue, vol%, max	3	3	3	3	--	3
Carbon Residue on 10% Bottoms, mass%, max 4/	0.10	0.15	0.35	0.20	0.35	0.35
Sulfur, mass%, max 5/	0.25	0.50	0.50	0.30	0.7	0.7 (or legal)
Copper Strip Corrosion, 3 hr at 50°C, max rating	3	3	3	1	3	3
Ash, mass%, max	0.01	0.01	0.01	0.02	0.01	0.01
Accelerated Stability, Total Insolubles, mg/100 mL, max	1.5	1.5	1.5	1.5	--	5.0
Neutralization Number, TAN, max	0.05	--	--	0.10	--	--
Particulate Contamination, mg/L, max	10	10	10	10	--	15
Cetane Number, min 6/	40	40	40	45	37	35 7/

1/ DF-2 intended for entry into the Central European Pipeline System shall have a minimum value of 58°C.

2/ As specified by the procuring activity. DF-2 for Europe and S. Korea shall have a maximum limit of -13°C.

3/ As specified by the procuring activity. DF-2 for Europe and S. Korea shall have a maximum limit of -18°C.

4/ If the fuel contains cetane improvers, the test must be performed on the base fuel blend only.

5/ Diesel fuel intended for consumption in southern California shall meet the requirements of the Southern California Air Quality Management District and Air Resources Board, which currently limits sulfur in diesel fuel to 0.05 mass% maximum.

6/ If cetane quality is determined as calculated cetane index, the minimum cetane index shall be 43 for grades DF-A, DF-2, and CONUS DF-2.

7/ High altitudes may require higher cetane numbers.

APPENDIX E

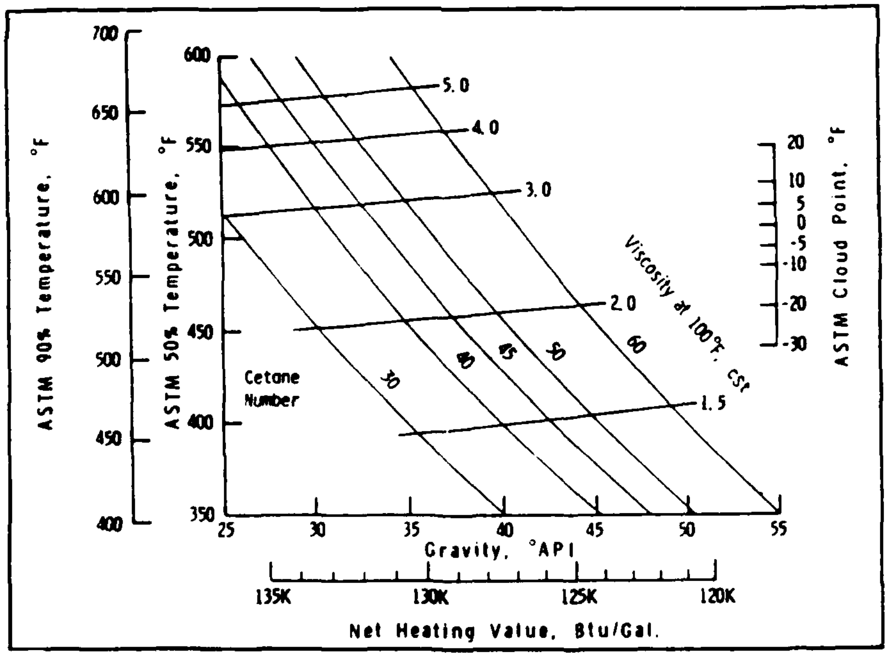
Interrelationship of Physical/Chemical Properties of Fuels

APPENDIX E

Interrelationship of Physical/Chemical Properties of Fuels

A chart showing the approximate relationship between 50-percent and 90-percent recovery temperatures from the ASTM distillation, API gravity, cetane number, viscosity, cloud point, and net heating value is shown below. These interrelationships may not be applicable to all distillate fuels produced from current crude oils by current refining processes. Because of these limitations, this chart should only be used to estimate fuel properties in the absence of complete data, and should not be used to establish specifications.

It can be noted, however, that, in general, the higher 90-percent distillation point fuel coupled to lower °API gravity and higher viscosity give higher net heating value fuels, which can show increased mission range compared to less viscous lower boiling point fuels having high API gravities.



Related properties of distillate diesel fuels

(Source: "Update Proposed for Diesel Fuel Specs.," Automotive Engineering, Vol. 78, No. 11, pp. 34-40, 1970.)

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US ARMY DEPOT SYSTEMS CMD
ATTN: AMSDS-RM-EFO 1
CHAMBERSBURG PA 17201

CDR
US ARMY LEA
ATTN: DALO-LEP 1
NEW CUMBERLAND ARMY DEPOT
NEW CUMBERLAND PA 17070

HQ, EUROPEAN COMMAND
ATTN: J4/7-LJPO (LTC WEINER) 1
VAIHINGEN, GE
APO NY 09128

CDR
US ARMY FOREIGN SCIENCE & TECH
CENTER
ATTN: AIAST-RA-ST3 (MR BUSI) 1
AIAST-MT-1 1
FEDERAL BLDG
CHARLOTTESVILLE VA 22901

CDR
US ARMY GENERAL MATERIAL &
PETROLEUM ACTIVITY
ATTN: STRGP-PW (MR PRICE) 1
BLDG 247, DEFENSE DEPOT TRACY
TRACY CA 95376-5051

CDR
US ARMY ORDNANCE CENTER &
SCHOOL
ATTN: ATSL-CD-CS 1
ABERDEEN PROVING GROUND MD
21005

CDR
AMC MATERIEL READINESS SUPPORT
ACTIVITY (MRSA)
ATTN: AMXMD-MO (MR BROWN) 1
LEXINGTON KY 40511-5101

HQ, US ARMY T&E COMMAND
ATTN: AMSTE-TO-O 1
AMSTE-TE-T (MR RITONDO) 1
ABERDEEN PROVING GROUND MD
21005-5006

CDR
US ARMY ARMAMENT RESEARCH,
DEVELOPMENT & ENGRG CTR
ATTN: AMSMC-LC 1
AMSMC-SC 1
DOVER NJ 07801-5001

CDR
CONSTRUCTION ENG RSCH LAB
ATTN: CERL-EM 1
CERL-ES (MR CASE) 1
P O BOX 4005
CHAMPAIGN IL 61820

TRADOC LIAISON OFFICE
ATTN: ATFE-LO-AV 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

HQ
US ARMY TRAINING & DOCTRINE CMD
ATTN: ATCD-SL-5 1
FORT MONROE VA 23651-5000

CDR
US ARMY NATICK RES & DEV CENTER
ATTN: STRNA-YE (DR KAPLAN) 1
STRNA-U 1
NATICK MA 01760-5000

CDR
US ARMY QUARTERMASTER SCHOOL
ATTN: ATSM-CD 1
ATSM-PFS (MR ELLIOTT) 1
FORT LEE VA 23801

DIRECTOR
US ARMY RSCH & TECH ACTIVITIES (AVSCOM)
PROPULSION DIRECTORATE
ATTN: SAVDL-PL-D (MR ACURIO) 1
21000 BROOKPARK ROAD
CLEVELAND OH 44135-3127

CDR
US ARMY TRANSPORTATION SCHOOL
ATTN: ATSP-CD-MS (MR HARNET) 1
FORT EUSTIS VA 23604-5000

PROJ MGR, PATRIOT PROJ OFFICE
ATTN: AMCPM-MD-T-C 1
U.S. ARMY MISSILE COMMAND
REDSTONE ARSENAL AL 35898

HQ, US ARMY ARMOR CENTER AND FORT KNOX
ATTN: ATSB-CD 1
FORT KNOX KY 40121

CDR
COMBINED ARMS COMBAT DEVELOPMENT ACTIVITY
ATTN: ATZL-CAT-E 1
FORT LEAVENWORTH KS 66027-5300

CDR
US ARMY LOGISTICS CTR
ATTN: ATCL-MS (MR A MARSHALL) 1
ATCL-C 1
FORT LEE VA 23801-6000

PROJECT MANAGER
PETROLEUM & WATER LOGISTICS
ATTN: AMCPM-PWL 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

CDR
US ARMY FIELD ARTILLERY SCHOOL
ATTN: ATSF-CD 1
FORT SILL OK 73503-5600

CDR
US ARMY ENGINEER SCHOOL
ATTN: ATZA-TSM-G 1
ATZA-CD 1
FORT BELVOIR VA 22060-5606

CDR
US ARMY INFANTRY SCHOOL
ATTN: ATSH-CD-MS-M 1
FORT BENNING GA 31905-5400

DIR
US ARMY MATERIALS TECHNOLOGY LABORATORY
ATTN: SLCMT-M 1
SLCMT-MCM-P (DR FOPIANO) 1
WATERTOWN MA 02172-2796

CDR
US ARMY ARMOR & ENGINEER BOARD
ATTN: ATZK-AE-AR 1
FORT KNOX KY 40121

CDR
US ARMY MEDICAL R&D LABORATORY
ATTN: SGRD-USG-M (MR EATON) 1
FORT DETRICK, MD 21701

CDR
US ARMY AVIATION CTR & FT RUCKER
ATTN: ATZQ-DI 1
FORT RUCKER AL 36362

DEPARTMENT OF THE NAVY

CDR
NAVAL AIR PROPULSION CENTER
ATTN: PE-33 (MR D'ORAZIO) 1
PE-32 (MR MANGIONE) 1
P O BOX 7176
TRENTON NJ 06828

CDR
NAVAL SEA SYSTEMS CMD
ATTN: CODE 05M4 1
WASHINGTON DC 20362-5101

CDR
DAVID TAYLOR RESEARCH CTR
ATTN: CODE 2830 (MR SINGERMAN) 1
CODE 2759 (MR STRUCKO) 1
CODE 2831 1
ANNAPOLIS MD 21402-5067

JOINT OIL ANALYSIS PROGRAM - TECHNICAL SUPPORT CTR 1
BLDG 780
NAVAL AIR STATION
PENSACOLA FL 32508-5300

CDR
NAVAL SHIP ENGINEERING CENTER
ATTN: CODE 6764 1
PHILADELPHIA PA 19112

PROJ MGR, M60 TANK DEVELOPMENT
ATTN: USMC-LNO 1
US ARMY TANK-AUTOMOTIVE COMMAND (TACOM)
WARREN MI 48397

CDR
NAVAL AIR SYSTEMS CMD
ATTN: CODE 53645 (MR MEARNS) 1
WASHINGTON DC 20361

CDR
NAVAL AIR DEVELOPMENT CTR
ATTN: CODE 6061 1
WARMINSTER PA 18974

CDR
NAVAL RESEARCH LABORATORY
ATTN: CODE 6170 1
CODE 6180 1
CODE 6110 (DR HARVEY) 1
WASHINGTON DC 20375-5000

CDR
NAVAL FACILITIES ENGR CTR
ATTN: CODE 1202B (MR R BURRIS) 1
200 STOVAL ST
ALEXANDRIA VA 22322

DEPUTY COMMANDING GENERAL
US MARINE CORPS RESEARCH, DEVELOPMENT & ACQUISITION CMD
ATTN: CBAL 1
QUANTICO VA 22134-5080

OFFICE OF THE CHIEF OF NAVAL RESEARCH
ATTN: OCNR-126 (DR ROBERTS) 1
ARLINGTON, VA 22217-5000

CDR
NAVY PETROLEUM OFC
ATTN: CODE 43 (MR LONG) 1
CAMERON STATION
ALEXANDRIA VA 22304-6180

DEPARTMENT OF THE AIR FORCE

HQ, USAF
ATTN: LEYSF (COL LEE) 1
WASHINGTON DC 20330

CDR
USAF 3902 TRANSPORTATION SQUADRON
ATTN: LGTVP (MR VAUGHN) 1
OFFUTT AIR FORCE BASE NE 68113

CDR
US AIR FORCE WRIGHT AERONAUTICAL LAB
ATTN: AFWAL/POSF 1
AFWAL/POSL (MR JONES) 1
AFWAL/MLSE 1
AFWAL/MLBT (MR SNYDER) 1
WRIGHT-PATTERSON AFB OH
45433-6563

CDR
SAN ANTONIO AIR LOGISTICS CTR
ATTN: SAALC/SFT (MR MAKRIS) 1
SAALC/MMPRR 1
KELLY AIR FORCE BASE TX 78241

CDR
DET 29
ATTN: SA-ALC/SFM 1
CAMERON STATION
ALEXANDRIA VA 22314

HQ AIR FORCE SYSTEMS CMD
ATTN: AFSC/DLF (DR DUES) 1
ANDREWS AFB MD 20334

CDR
WARNER ROBINS AIR LOGISTIC CTR
ATTN: WRALC/MMTV 1
ROBINS AFB GA 31098

OTHER GOVERNMENT AGENCIES

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
ATTN: AWS-110 1
800 INDEPENDENCE AVE, SW
WASHINGTON DC 20590

NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION 1
LEWIS RESEARCH CENTER
CLEVELAND OH 44135

US DEPARTMENT OF ENERGY
ATTN: MR ECKLUND 1
MAIL CODE CE-151
FORRESTAL BLDG.
1000 INDEPENDENCE AVE, SW
WASHINGTON DC 20585

ENVIRONMENTAL PROTECTION
AGENCY
AIR POLLUTION CONTROL 1
2565 PLYMOUTH ROAD
ANN ARBOR MI 48105

END
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